PLATE I

MARS
SINUS TITANUM
NOVEMBER, 1894

LOWELL OBSERVATORY
Flagstaff, A. T. 1894

MARS

BY

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TO

PROFESSOR WILLIAM EDWARD STORY

SOMETIME AT FLAGSTAFF HIMSELF

THIS NEWS FROM A NEIGHBOR

IS INSCRIBED

PREFACE

This book is the result of a special study of the planet made during the last opposition, at an observatory put up for the purpose of getting as good air as practicable, at Flagstaff, Arizona. A steady atmosphere is essential to the study of planetary detail: size of instrument being a very secondary matter. A large instrument in poor air will not begin to show what a smaller one in good air will. When this is recognized, as it eventually will be, it will become the fashion to put up observatories where they may see rather than be seen.

Next to atmosphere comes systematic study. Of the extent to which this was realized at Flagstaff, I need only say that the planet was observed there from May 24, 1894, to April 3, 1895, during which time, to mention nothing else, 917 drawings and sketches were made of it. Prof. W. H. Pickering and Mr. A. E.

Douglass were associated with me in the observations herein described.

Such as care to see the original data more technically and minutely treated will find them in the first volume of the Annals of this observatory.

LOWELL OBSERVATORY,
November, 1895.

CONTENTS

LIST OF ILLUSTRATIONS

MARS

I

GENERAL CHARACTERISTICS

I. AS A STAR

Once in about every fifteen years a startling visitant makes his appearance upon our midnight skies, — a great red star that rises at sunset through the haze about the eastern horizon, and then, mounting higher with the deepening night, blazes forth against the dark background of space with a splendor that outshines Sirius and rivals the giant Jupiter himself. Startling for its size, the stranger looks the more fateful for being a fiery red. Small wonder that by many folk it is taken for a portent. Certainly, no one who had not followed in their courses what the Greeks so picturesquely called "the wanderers" (οἱ πλανῆται) would recognize in the apparition an orderly member of our own solar family. Nevertheless, one of the wanderers it is, for that star is the planet Mars, large because for the moment near, having in due course again been overtaken by the Earth, in

her swifter circling about the Sun, at that point in space where his orbit and hers make their closest approach.

Although the apparent new-comer is neither new nor intrinsically great, he possesses for us an interest out of all proportion to his size or his relative importance in the universe; and this for two reasons: first, because he is of our own cosmic kin; and secondly, because no other heavenly body, Venus and the Moon alone excepted, ever approaches us so near. What is more, we see him at such times better than we ever do Venus, for the latter, contrary to what her name might lead one to expect, keeps herself so constantly cloaked in cloud that we are permitted only the most meagre peeps at her actual surface; while Mars, on the other hand, lets us see him as he is, no cloud-veil of his, as a rule, hiding him from view. He thus offers us effective opportunities for study at closer range than does any other body in the universe except the Moon. And the Moon balks inquiry at the outset. For that body, from which we might hope to learn much, appears upon inspection to be, cosmically speaking, dead. Upon her silent surface next to nothing now takes place save for the possible crumbling in of a crater wall. For all practical purposes Mars is our nearest neighbor in space. Of all the orbs about us, therefore, he holds out most

omise of response to that question which man
tinctively makes as he gazes up at the stars:
hat goes on upon all those distant globes?
e they worlds, or are they mere masses of
tter? Are physical forces alone at work
ere, or has evolution begotten something
re complex, something not unakin to what
know on Earth as life? It is in this that
s the peculiar interest of Mars.

That just as there are other masses of matter
an our globe, so there are among them other
rlds than ours is an instant and inevitable
erence from what we see about us. That we
the only part of the cosmos possessing what
are pleased to call mind is so earth-centred
supposition, that it recalls the other earth-
ntred view once so devoutly held, that our
le globe was the point about which the
ole company of heaven was good enough
turn. Indeed, there was much more reason
think that then, than to think this now, for
ere was at least the appearance of turning,
ereas there is no indication that we are sole
nizens of all we survey, and every inference
at we are not.

That we are in some wise kin to all the rest
the cosmos, science has been steadily demon-
ating more and more clearly. The essential
eness of the universe is the goal to which all
arning tends. Just as Newton proved all the

planets to obey a common force, the Sun ; just as Laplace showed it to be probable that we were all evolved from one and the same primal nebula; so more recently the spectroscope has revealed unsuspected relationship betwixt us and the stars. Matter turns out to be but common property; and the very same substances with which we are so familiar on the Earth, iron, magnesium, sodium, and so forth, prove present on those far-off suns that strew the depths of space. Only in detail does everything differ.

So much for matter. As for that manifestation of it known as mind, modesty, if not intelligence, forbids the thought that we are sole thinkers in all we see. Indeed, we seldom stop in our locally engrossing pursuits to realize how small the part we play in the universal drama. Let us consider for a moment how we should appear, or, more exactly, not appear, could we get off our world and scan it from without. If distance could thus reduce for us the scale upon which the universe is fashioned to one we could take in, that on which the Earth should be represented by a good-sized pea, with a grain of mustard seed, the Moon, circling about it at a distance of seven inches, the Sun would be a globe two feet in diameter, two hundred and fifteen feet away. Mars, a much smaller pea, would circle around the two-foot globe three hundred and twenty-five feet from its surface ;

Jupiter, an orange, at a distance of a fifth of a mile; Saturn, a small orange, at two fifths of a mile; and Uranus and Neptune, good-sized plums, three quarters of a mile and a mile and a quarter away, respectively. On this same scale the nearest star would lie eight thousand miles off, and an average third-magnitude star at about the present distance of our Moon; that is, on a scale upon which the Moon should be but seven inches off, the average star would still be as far from us as the Moon is now. Now when we think that each of these stars is probably the centre of a solar system grander than our own, we cannot seriously take ourselves to be the only minds in it all.

Probable, however, as extra-terrestrial life in general is, it is another matter to predicate it in any particular case. Nevertheless, if it exist it must exist somewhere, and the first place to scan is the place we can scan best. Now the Moon appears to be hopelessly dead. Mars, therefore, becomes of peculiar interest, and it was in hope of learning something on the subject that the observations about to be described in this book were made. Before proceeding, however, to an account of what in consequence we have learned about our neighbor, a couple of misapprehensions upon the subject, — not confined, I am sorry to say, wholly to the lay mind, — must first be corrected. One of these is

that extra-terrestrial life means extra-terrestrial human life. Such an inference recalls to my mind the exclamation of an innocent globe-trotter to a friend of mine in Japan once, a connoisseur of Japanese painting, upon being told that the Japanese pictures were exceedingly fine. "What!" the globe-trotter exclaimed in surprise, "do the Japanese have pictures,—real pictures, I mean, in gilt frames?" The existence of extra-terrestrial life does not involve "real life in trousers," or any other particular form of it with which we are locally conversant. Under changed conditions, life itself must take on other forms.

The next point is as to what constitutes proof. Now, between the truths we take for granted because of their age, and those we question because of their youth, we are apt to forget that in both proof is nothing but preponderance of probability. The law of gravitation, for example, than which we believe nothing to be more true, depends eventually, as recognized by us, upon a question of probability; and so do the thousand and one problems of daily life upon so many of which we act unhesitatingly and should be philosophic fools if we did not. All deduction rests ultimately upon the data derived from experience. This is the tortoise that supports our conception of the cosmos. For us, therefore, the point at issue in any

theory is not whether there be a possibility of its being false, but whether there be a probability of its being true. This, which is evident enough when squarely envisaged, is too often lost sight of in discussing theories on their road to recognition. Negative evidence is no evidence at all, and the possibility that a thing might be otherwise, no proof whatever that it is not so. The test of a theory is, first, that it shall not be directly contradicted by any facts, and secondly, that the probabilities in its favor shall be sufficiently great.

As to what constitutes sufficiency it is important to bear in mind one point, namely, that the odds that a thing is true from the fact that two or more witnesses agree on the same statement is not the sum of the odds that each tells the truth, but the product of those odds.[1] Therefore, if the chances for the truth of a theory, in consequence of its explaining a certain set of details, be three to one, and because of its explaining another set, — for the purposes of argument unrelated to the first, — four to one, then the chances in its favor from its explaining both sets are not seven to one but twelve to one. If it explains a third set whose independently resulting odds are of five to one, the chances in its favor become, from its explaining all three sets, not twelve to one but sixty to one; if a fourth set be added, with further odds of five to

[1] See Lacroix, *Traité Elémentaire des Probabilités*, p. 220.

one, the sum total from the four becomes not seventeen to one but three hundred to one in favor of its being true. It will be seen how rapidly the probability of the truth of a theory mounts up from the amount of detail it explains. This law is to be remembered throughout the coming exposition, for whatever the cogency of each detail of the argument in itself, the concurrence of all renders them not simply additionally but multiplicitly effective. That different lines of induction all converge to one point proves that point to be the radiant point of the result.

II. ORBIT

To determine whether a planet be the abode of life in the least resembling that with which we are acquainted, two questions about it must be answered in turn: first, are its physical conditions such as render it, in our general sense, habitable; and secondly, are there any signs of its actual habitation? These problems must be attacked in their order, for unless we can answer the first satisfactorily, it were largely futile to seek for evidence of the second.

Thoroughly to appreciate, then, the physical condition of Mars, we must begin at the beginning of our knowledge of the planet, since every detail will be found to play its part in the final result. I shall therefore give in a word or two

the general facts known about the planet, before taking up the observations which make the subject matter of this book. The first of these general facts is the path the planet describes about the Sun. Who first found out that the ruddy star we call Mars was not like the rest of the company about him we do not know; possibly some, to fame unknown, Chaldean shepherd alone with the night upon the great Chaldean plains. With the stars for sole companions while his sheep slept, he must, as he watched them night after night, have early recognized that they always kept the same configuration. They rose and set, but they all rose and set together. But one night he thought he noticed that one of them had changed its place with reference to the rest. A few nights later he became sure of it. One of the immovable had patently moved. That memorable though unremembered night marked the birth of our acquaintance with the rest of the universe.

Whether the midnight pioneer was Chaldean or Assyrian or of some other race, certain it is that to the Egyptians we owe the first systematic study of the motions of this and of four other roving stars, and to the Greeks whom they taught, the name by which we know them, that of planets, meaning merely wanderers. Since then, as we know, many others of like habit have been added to the list.

Now, from observations of the apparent places of a planet, it is possible to determine the relative path of the planet in space as compared with the path of the Earth. This Kepler did from observations of Tycho Brahe's, and showed the wanderers to belong to a system of bodies, all revolving about the Sun in various elliptic orbits, the Sun being at the focus of each ellipse. He also found that the line connecting each planet with the Sun passed over equal areas in equal times, and thirdly, that the squares of the times were as the cubes of the major axes of the orbits. From these three "laws" Newton deduced the fact that the force controlling the planets was directed toward the Sun, that it varied inversely as the square of the distance, and that it was the same in origin for all. This is the so-called law of gravitation, and this is the way in which it was discovered. We do not yet know why gravity so acts, but it is interesting to note that it follows the simple law of geometrical expansion, diminishing in exact ratio to the space it fills, just like electricity or light. It may, therefore, also be a wave motion.

Thus all the wanderers proved to be associated in common dependence on the Sun, and among the members of the solar family thus recognized Mars was found to hold the position next exterior to the Earth, and the path he fol-

lowed in his circuit of the Sun to be situated with regard to the Earth's as in the following diagram.

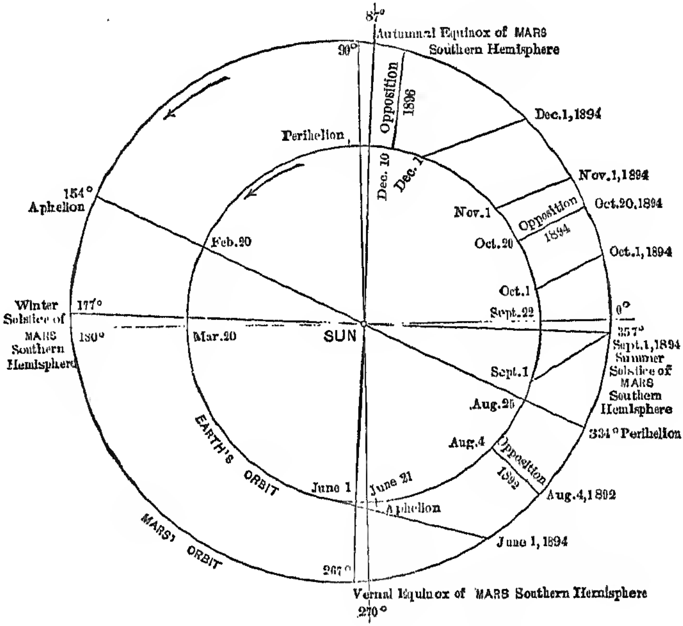


Diagram of the Orbits of Mars and the Earth.

On consulting the diagram we shall at once perceive why it is that every fifteen years Mars becomes so unusually bright as to seem, to one who has not kept track of him, a new and startling star. His orbit, it will be seen, is an ellipse of some eccentricity, and deviates in consequence considerably from a circle. The point marked Perihelion denotes the point where the planet is nearest the Sun; the point marked

Aphelion, the point where the planet is the most remote from the Sun. In like manner the points marked Perihelion and Aphelion on the inner circle show the corresponding points of the Earth's orbit, which is much more nearly circular. Now as the two planets revolve in different periods of time, Mars taking 686.98 of our days to complete his circuit, and the Earth 365.26 days to complete hers, the one planet will overtake the other only once every two years and two months or so. Meanwhile they are at great distances apart. But even when they do meet, they do not always meet equally near. For the one orbital period is not an exact multiple of the other, and as the orbits are both ellipses, it is evident that these meetings of the two planets will occur at different points of their orbits, and, therefore, at different distances. If the meeting occur when Mars is in perihelion the planets approach one another within 35,050,000 miles; if in aphelion, only within 61,000,000 miles.

But even this difference in distance does not measure the full extent of the variation in brilliancy. As the brightness of an illuminated body varies inversely as the square of its distance from the source of light, and as the total amount of light it reflects to an observer varies inversely as the square of his distance from it, it makes every difference in the apparent bril-

liancy of a body how the body is situated, both with regard to the source of light and with regard to the observer. Now it so chances that at the meetings of Mars with the Earth these two factors attain their maximum effects nearly together, and similarly with their minimum. For at the times when we are closest to Mars, Mars is nearly at his closest to the Sun, and reversely when we meet him at the opposite part of his orbit. It thus comes about that at some meetings, — oppositions, they are called, because Mars then is in the opposite part of the sky from the Sun, — the planet appears four and one half times as bright as at others. Here, then, we have the explanation of the planet's great changes in appearance, changes so great as to deceive any one who has not followed its wanderings, into the belief that it is some new and portentous apparition.

Important as is the ellipse in which Mars moves with regard to his visibility by us, it is considerably more important as regards the physical condition of the planet itself. For the Sun being situated at one of the foci of his orbit, the motion of the planet sweeps him now near to, now far from that dispenser of light and warmth; and the amount of both which the planet receives varies just like gravity with his distance from their source. Now the eccentricity of the orbit of Mars is such that

when nearest the Sun his distance is 129,-500,000 miles, when at his mean distance 141,500,000 miles, and when most remote 154,500,000 miles. The proportion of light and heat he receives respectively is therefore roughly as 16 to 20 to 24; or half as much again at certain times as at others.

So much in our knowledge of Mars is pre-telescopic. Men might have and practically did learn this much without ever seeing the planet other than as a point of light. Its orbit was tolerably accurately known and could have been known still more accurately without telescopic aid; not so, until we become much more nearly omniscient than we at present are, the planet's self.

III. SIZE AND SHAPE

With the telescope we enter upon a new phase in our knowledge of the planet: the determination of its shape and size.

The relative plan of the solar system can be learned with great accuracy from observations of the motions of its members; not so easily learned is the scale upon which it is constructed. Although the former is intrinsically a very complicated, the latter a very simple problem, two characteristics of the actual system make it possible to solve the former much more nearly than the latter. One of these

characteristics is the fact that the distances between the masses which compose the system are very much greater than the dimensions of the masses themselves, of quite a higher order of magnitude. The diameters of the planets are measured by thousands of miles, the distances between them by tens of millions. The second characteristic consists in the approximately spherical shape of the planets themselves, and in the fact that by a mathematical consequence of the actual law of gravitation a sphere acts upon any outside body as if all its mass were concentrated at its centre, a most interesting peculiarity not true under many other supposable laws. These two facts very materially simplify the problem of the motions of celestial mechanics.

But just as the first of these peculiarities helps us to comprehension of the relative dimensions of the solar system, so does it hinder us in determining its actual dimensions. For this determination depends upon a problem in celestial surveying, the finding the distance to a body by measuring the angle it subtends from the two ends of a base-line. Now, as unfortunately we cannot get off the earth for the purpose, our base-line is at most the diameter of the earth itself, and as the distance to the other body immensely exceeds our own size, the angle to be measured becomes so excessively small as

to be very difficult to determine with accuracy. Fortunately this is matter chiefly of theoretic regret, as we now know the actual sizes to within a degree of exactness practically sufficient for most purposes but perturbations; to within about $\frac{1}{300}$ part of the whole, so far as our ultimate measure is concerned, the distance we are off from the Sun.

A good idea of the method and some appreciation of the difficulty involved in it can be got by considering a precisely similar case, that of determining the distance of a spire a mile and three fifths away by shutting first one eye and then the other and noting the shift of the spire against its background. It is needless to add that without telescopic aid the determination is impossible, and that it is exceeding difficult with it.

Nevertheless, from the distance of the Sun determined in this manner, we find from measurements of the apparent disk of the planet made at Flagstaff that Mars is about 4,215 miles in diameter. This makes his surface a little more than a quarter that of the Earth and his volume about one seventh of hers.

The next point to find out is his mass, that is, the amount of matter he contains. This is very easy to determine when a planet has a satellite, and very difficult to determine when

a planet has not. The reason is this: the mass of a body is known from the pull it exerts, inasmuch as this pull depends, by the law of gravitation, upon its mass and the square of its distance. If then we know the pull and the distance from which it is exerted, we can find the mass. Now we gauge the pull from its effects in causing some other body to move. By measuring, therefore, the motion of this other body, we learn the mass of the first one. To get this accurately the motion must be large enough to admit of satisfactory measurement in the first place, and be as uncomplicated with motions due to pulls of other bodies as possible, in the second. As each body pulls every other, and it is only their relative displacement we can measure, as we have no foothold in space, even the case of only two bodies presents difficulties of apportionment. We can learn the aggregate mass of the two, but not the separate mass of either alone unless it so happen that the mass of one is so insignificant compared with the other that the mass of that other may be taken as the mass of both. Now this is substantially realized in the case of the solar system. Owing to the greatly disproportionate size of primary and secondary bodies in it, the great size of the Sun as compared with that of any of the planets, and the great size of the planets as compared with their satellites

(with the exception of the Moon, and she, fortunately, is an only child), the determination of the mass of the smaller by measurement of its motion about the larger, — as if only the pair of bodies under consideration existed, and the mass of both were concentrated in the greater of the two, — is very nearly exact. In consequence each planet discloses with some accuracy the mass of the Sun, but tells next to nothing about its own mass; and in the same way each satellite reveals the mass of its primary. The mass of a planet possessing a satellite is, therefore, easy of determination. Not so that of one which travels unattended. The only way to obtain its mass is from the perturbations or disturbing pulls it exerts upon the other planets, or upon stray comets from time to time, and these disturbances are, by the nature of the case, of a much smaller order of magnitude, to say nothing of the fact that all act coincidently to increased difficulty of disentanglement. The practical outcome of this in the case of Mars was that before his satellites were discovered the values obtained for his mass ranged all the way from $\frac{1}{3700000}$ to $\frac{1}{2500000}$ of the mass of the Sun, or, in other words, varied fifty per cent. His insignificant satellites, however, and just because they are insignificant, have made it possible to learn his mass with great exactness. It turns out to

be $\frac{1}{3093500}$ of that of the Sun, or $\frac{10}{94}$ of that of the Earth.

Knowing his mass, we know his average density, since to find it we have but to divide his mass by his volume. It proves to be $\frac{72}{100}$ of that of the Earth. We also learn the force of gravity at his surface, inasmuch as this is directly as his mass and inversely as the square of his radius. It comes out $\frac{38}{100}$ of that of the Earth. In consequence, all things there would weigh but $\frac{38}{100}$ of their weight on earth; a man, for example, weighing 150 pounds here would weigh but 55 pounds if transported to the surface of Mars, and all manual labor would be lightened threefold.

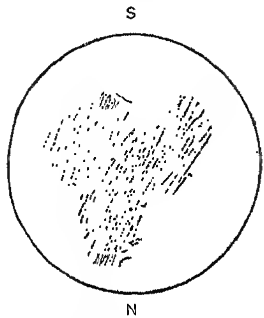
So soon as the planet was scanned telescopically, he was seen to present a disk, round at times, at other times lacking somewhat of a perfect circle, showing like the Moon when two days off from full. Such appearance visibly demonstrated, first, that he was not a self-luminous body, and secondly, that he revolved about the Sun outside of the Earth. A glance at the diagram of the orbit will make the latter point clearer. If we draw a line from the Sun to the centre of Mars and pass a plane through the planet perpendicular to this line and to the plane of his orbit, this plane will divide the illumined half of him from the unillumined half. If now we draw another line from any point

of the Earth's orbit to Mars' centre, and pass a plane similarly perpendicular to that, it will cut off the hemisphere we see at any moment from the one we do not. As the two lines do not in general coincide, it will appear that in certain positions, in fact in all but two, Mars must present to us a face partly steeped in daylight, partly shrouded in night; in short, that he shows gibbous like the Moon when she is between the half and the full. This accounts for the look of the drawings made during June, 1894, in which from a seventh to a sixth of the disk is wanting on the left.[1] By drawing lines from his centre to more than one position occupied by the Earth it will be seen that this lacking lune reaches a maximum when the Earth as viewed from Mars is at extreme elongation from the Sun, and that the amount of the phase at such time exactly equals the number of degrees of this elongation. For example, on the sixteenth of last June the lacking lune amounted to 47°, that is, the Earth was then evening star upon the Martian twilight skies at an angular distance of 47° from the Sun, about what Venus seems to us at her extreme elongation. In fact, to Mars we occupy much the same astronomical position that Venus does to us.

To Huyghens we owe the first really impor-

[1] Plates XV., XVI., XVII.

tant telescopic observation upon the planet. On November 28, 1659, at 7 P. M., he made the first drawing of the planet worthy the name, for on it is the first identifiable feature ever made out by man on the surface of Mars. This feature is the Hourglass Sea, now more commonly known as the Syrtis Major. The accompanying cut of it is reproduced from Flammarion. If the dark patch in it be compared with the markings in the other pictures of the planet, shown later in this book, it will be seen that the patch can be none other than the Hourglass Sea.



Huyghens' drawing of the Syrtis Major, Nov. 28, 1659, 7 P. M. Reproduced from Flammarion's "La Planète Mars."

Now, innocent as it looks of much detail, Huyghens' drawing is perhaps the most important one of Mars that has ever been made. For, from his observations of the spot it depicts at successive dates, he was able to prove that Mars rotated on his own axis, and to determine the time of that rotation, about 24 hours. As he subsequently came to doubt his results, the honor of the discovery rests with Cassini, who, in 1666, definitely determined that the planet rotated in 24 hours 40 minutes. Thus was it

first learned that Mars had a day, and that its length was not far from the length of our own.

The importance of these earliest pictures of Mars has not lapsed with the lapse of time. By comparison of this and other early drawings with modern ones, has been deduced a very accurate value of the length of the Martian day (its sidereal day), a determination accurate to the tenth of a second. It amounts to 24 hours, 37 minutes, 22.7 seconds. Our sidereal day, that is, the day reckoned by the stars, not by the Sun, is roughly 23 hours, 56 minutes; so that the Martian day is about 40 minutes longer than our own. The result is not given here closer than the tenth of a second, because the Flagstaff observations have shown that the value of the length of the Martian day hitherto accepted is probably a trifle too small.

From the discovery of the rotation followed the approximate position of the planet's poles. Round about the poles so determined appeared two white patches, the first study of which we owe to Maraldi. They are the planet's polar caps. They are to be detected with the smallest modern telescope.

The apparent position of the planet poles as presented to the Earth gives the tilt of the planet's axis to the plane of its orbit. It turns out to be about 25°. This is very nearly the same as the Earth's axial tilt to the plane of

her orbit, which is 23° 24′. As the inclination of the axis to the plane of the orbit determines the seasons, we see that not only has Mars its spring, summer, autumn, and winter, but that these are not very unlike our own.

It is not uninteresting to inquire in what the difference consists. The slight difference of tilt in the Martian axis would slightly extend the breadth of the tropical and the polar regions at the expense of the temperate ones, and thus accentuate the seasons, but the chief seasonal contrast between Mars and the Earth would come in in consequence of the much greater eccentricity of Mars' orbit. For the more eccentric the ellipse, the greater the variation in the planet's velocity at different parts of it, inasmuch as the Sun pulls the planet toward himself with a force depending on his distance. The less this distance, the greater the angular velocity. But the angular velocity determines the length of the seasons upon a planet whose pole of rotation is tilted to the plane of its orbit, like the Earth or Mars. The greater the eccentricity of the ellipse, therefore, the greater the difference in the length of the seasons. In the case of the Earth the difference is about eight days, winter in the northern hemisphere being eight days shorter than summer. In the case of Mars, owing to the much greater eccentricity of his orbit combined with his longer

period, the difference amounts to 74 days. In one hemisphere winter is long and cold, summer short and hot; in the other winter and summer interchange. Owing to the present position of the line of apsides, the line connecting the points of Mars' nearest approach to and farthest recession from the Sun, the former hemisphere happens to be the southern one; the latter, the northern. The lengths of their respective seasons are as follows: —

In the northern hemisphere, winter lasts 147 of his own days; spring, 191 days; summer, 181 days; autumn, 149 days; while in the southern hemisphere, winter lasts 181 days; spring, 149 days; summer, 147 days; autumn, 191 days.

Curiously enough, an analogous distribution of heat and cold occurs also at the present time in the case of the Earth; its axis and line of apsides holding the same relation to each other that the Martian ones do. This similarity of aspect is, as we shall see later, apparently very curiously reproduced in certain peculiarities of the surfaces of the two planets. But with Mars the result is much more marked on account of the greater eccentricity of his orbit, which is .0931 as against the Earth's .0168.

As even under these exaggerated conditions his two polar regions show much alike, modern theories about our glacial epochs are considerably shaken.

The last of the preliminary points to be taken up is the form of the planet. Consideration of it makes in some sort a bridge from the planet's past to its present. For its deviation from a perfect sphere tells us something of its history.

Between the shapes of the large planets, Jupiter, Saturn, Uranus, and probably Neptune, and those of the small ones, Mercury, Venus, the Earth, and Mars, there is a striking dissimilarity, the former being markedly oblate spheroids, the latter almost perfect spheres.

Into the cause of this, very interesting as it is, we have not here space to go. The effect, however, is so noticeable that while the most casual glance at the disk of Jupiter will reveal its ellipticity, the most careful scrutiny would fail to show Mars other than perfectly round.

Nevertheless, the planet is slightly flattened at the poles. Measures have repeatedly been made to determine the extent of this flattening, with surprisingly discordant results, most of the values being much too large.

Observations at Flagstaff during this last opposition have not only shown that most of the values were too large, but have revealed the cause of their discrepancy. There turns out to be a factor in the case, hitherto unsuspected, whose presence proves to be precisely such as would cause the observed variations in measurements. It not only accounts for the fact of

discrepancy, but for the further fact that the discrepancies should usually be on the side of an increase of the apparent polar flattening. This factor is the recognition of a perceptible twilight upon the planet, not only of enough account to be visible, but to have been actually measured, quite unconsciously, by Mr. Douglass, and disclosed only when the measures came to be compared with each other. Of this I shall speak more at length when we reach the subject of atmosphere. Here it is only necessary to say that the presence of a twilight fringing the surface of the planet would have the effect of increasing the apparent size of the equatorial diameter at all times, but to a different degree at different times, and almost always more than it would the polar one. In consequence, the polar flattening, which is the ratio borne by the difference of the equatorial and polar diameters to the equatorial diameter, would be seemingly increased.

The value of Mr. Douglass' measures is heightened by a certain happy event of an unprecedented nature, — the first observed disappearance of the polar cap, and that at the very time the most important measures were made. The presence of the polar cap enters as a disturbing element into measures of the planet's disk, on account of the increased irradiation it causes at the extremity of the polar diameter,

which makes the polar diameter measure more than it otherwise would. For the polar cap is the most brilliant part of the disk; and for the same reason that any bright body seems larger than a dark one of the same size, it dilates the planet unduly in that direction. The resulting effect is further complicated by the fact that the polar cap is eccentrically situated with regard to the pole of rotation, as we shall see later; and as the pole is tilted, the cap is sometimes on the edge of the disk and the irradiation in consequence large, and sometimes well on the disk itself where its irradiation is little or nothing. As the amount of its magnifying effect is not accurately known, there enters with it an unknown error. Now, last autumn Nature herself kindly eliminated this source of error.

The measures made by Mr. Douglass are thus entitled to special regard, not only because of their number (a great many of them were taken), but chiefly because Nature made the disturbing influence of the polar cap *nil*. When, in addition, the twilight arc is allowed for, the measures show a most satisfactory accordance and give for the value of the polar flattening $\frac{1}{190}$ of the equatorial diameter.

Now, it is interesting that this value should receive corroborative support from two quite different directions. The first of these is that $\frac{1}{190}$ is just about the flattening which would re-

sult from the most probable supposition we can make as to the past history of the planet. To show this we may take the case of the Earth. Investigations along several different lines all result in showing that the polar flattening of the Earth is almost exactly such as would result in a fluid body whose density from surface to centre increased according to the pressure and temperature of our Earth in the past, and which rotated with its present angular velocity. In the case of Mars, Tisserand has shown that the polar flattening under the influence of his present rotation would, if the increase of density in his strata were similar to the Earth's, be $\frac{1}{227}$ of his equatorial diameter. If, on the other hand, his mass were homogeneous, his polar flattening would be $\frac{1}{178}$. Now, in a fluid condition a body could not remain homogeneous, owing to the pressure exerted by the outer strata upon the inner ones, unless the matter of which it was composed were rigorously incompressible, which is certainly not the case with the Earth, and with quite equal certainty not the case with Mars. On the other hand, the increase of density from surface to centre is undoubtedly less in Mars than in the Earth, since the pressure depends upon the mass and the Earth's mass is nearly ten times that of Mars. Consequently, from this cause, the polar flattening should be somewhere between $\frac{1}{178}$ and $\frac{1}{227}$,

not far therefore from the value found above, $\frac{1}{190}$.

The second bit of corroborative testimony comes from the behavior of the satellites of the planet. Unlike a sphere, a spheroid acts unequally upon a body revolving about it in an ellipse inclined to its equator. The ring pulls the satellite now this way, now that, thus altering its nodes, that is, the points where the plane of its orbit crosses the planet's equator, and also its apsides, or the points in which the satellite's orbit is nearest and farthest from the planet. The effect of an equatorial protuberance tilted thus is to shift these points round the orbit, the line of nodes retrograding, while contrarily the line of apsides advances. From the speed with which these revolutions take place, it is possible to calculate the size of the bulge. Hermann Struve has just done this for the lines of apsides of the two satellites of Mars, and finds for the value for the consequent polar flattening of the planet $\frac{1}{190}$ of its equatorial diameter. From these two independent determinations we may conclude that the value found at Flagstaff is pretty nearly correct.

We find, then, that Mars is a little flatter than our Earth, though not noticeably so, the polar flattening amounting to about 22 miles.

The value, $\frac{1}{190}$, for his polar flattening, hints that at some past time Mars was in a fluid—

that is, a molten—condition, just as the Earth's polar flattening of $\frac{1}{303}$ similarly shows her to have been, and that in both cases the flattening was then impressed. Now, inasmuch as the tides, lunar and solar in the case of the Earth, solar practically alone in the case of Mars, have been slowing up the planet's rotation ever since this refrigeration happened, but as their respective rates of rotation still agree substantially with what a fluid condition demands, it is evident that in the case of neither planet could the cooling have begun so very long ago, but that it began longer ago for Mars than for the Earth.

In so far, then, we trace a certain similarity of development in the early chaotic stage of evolution of the two planets, a stage pre-natal to their career as worlds.

From these basic facts of size and shape we will now go on to more latter-day detail.

II

ATMOSPHERE

I. EVIDENCE OF IT

To all forms of life of which we have any conception, two things in nature are vital, air and water. A planet must possess these two requisites to be able to support any life at all upon its surface. For there is no creature, no plant, no anything endowed with the possibility of that kind of change we call life, which is not in some measure dependent upon both of them. How, then, is Mars off for air?

Fortunately for an answer to this question, air, in the post-chaotic part of a planet's career, plays as vital a rôle in the inorganic processes of nature as in the organic ones. By the post-chaotic period of a planet's history we may designate that time in its evolutionary existence which follows the parting with its own inherent heat. After its heat has gone from it, atmosphere becomes essential, not only to any form of life upon its surface, but to the production of any change whatever there. Without atmosphere all development, even the development

of decay, must come to a stand-still, when once what was friable had crumbled to pieces under the alternate roasting and refrigerating, relatively speaking, to which the body's surface would be exposed as it turned round on its axis into and out of the Sun's rays. Such disintegration once accomplished, the planet would roll thenceforth a mummy world through space.

An instance of this death in life we have exemplified by the nearest of the heavenly bodies, our own Moon. That cataclysmic changes once occurred there is still legible on her face, while the present well-nigh complete immutability of that face shows that next to nothing happens there now. Except for the possible tumbling in of a crater wall, such as seems to have taken place in the case of Linné a few years ago, all is now deathly still. But atmosphere is as absent as change. Whatever it may have had in the past, there is at present no perceptible air upon the surface of the Moon. And change *pro tanto* knows it no more.

With Mars it is otherwise. Over the surface of that planet changes do occur, changes upon a scale vast enough to be visible from the Earth. To appreciate the character and extent of these changes we will begin with the appearance of the planet last June.[1] From the drawings it will be seen that the general aspect of the

[1] Plates V., VI., VII. Uppermost figure.

planet's surface at that time was tripartite. Upon the top part of the disk, round what we know to be the planet's pole, appeared to be a great white cap. This was the planet's south polar cap. The south lay at the top, because all astronomical views are, for optical reasons, upside down; but, inasmuch as we never see the features otherwise, to have them right side up is not vital to the effect. Below the white cap lay a region chiefly bluish-green, interspersed, however, with portions more or less reddish-ochre. Below this, again, came a vast reddish-ochre stretch.

The first sign of change occurred in the polar cap. It proceeded slowly to dwindle in size. Such self-obliteration it has, with praiseworthy regularity, been seen to undergo once every two years since it was first seen by man. For nearly two hundred years now, it has been observed to wax and wane with clock-like precision, a precision timed to the change of season in the planet's year. During the spring, these snow-fields, as analogy at once guesses them to be, and as beyond doubt they really are, stretch in the southern hemisphere, the one presented to us at this last opposition, down to latitude sixty-five south and even further, covering thus more than the whole of the planet's frigid zone. As summer comes on, they dwindle gradually away, till by early au-

tumn they present but tiny patches a few hundred miles across. This year, for the first time in human experience, they melted, apparently, completely.

The history of the cap's vicissitudes we shall take up farther on in connection with the question of water. It is only necessary here to note that changes occurred in it.

The disappearance of the polar snows is by no means the only change discernible upon the surface of the planet. Several years ago Schiaparelli noticed differences in tint at successive oppositions both in the dark areas and in the bright ones. These, he suggested, might be due to seasons. At the last opposition, that of 1894, it was possible at Flagstaff, owing to the length of time the planet was kept under observation, to watch the changes occur; thus conclusively proving them to be changes of a seasonal character.

From early in June, which corresponded to the Martian last of April, to the end of November, which corresponded to the Martian last of August, the bluish-green areas underwent a marked transformation. During the summer of the Martian southern hemisphere, a wave of seasonal change swept down from the pole over the face of the planet. What and why it was we will examine in detail when we take up the question of water. Like the changes in the

polar cap, it suffices here to chronicle the fact that it took place; for the fact of its occurrence constitutes proof positive of the presence of an atmosphere.

A moment's consideration will show how absolutely positive this proof is. It is the inevitable deduction from the simplest of observed facts. Its cogency gains from its very simplicity. For it is independent of difficult detail or of doubtful interpretation. It is not concerned with what may be the constitution of the polar caps, nor with the character of the transformation that sweeps, wave-like, over the rest of the planet's face. It merely takes note that change occurs, and that note is final.

Now, since this was originally written, certain observations made at this observatory by Mr. Douglass have resulted apparently, most unexpectedly, in actually revealing this atmosphere to sight. Although the existence of an atmosphere is absolutely established by the above considerations, it is interesting to have ocular demonstration of it to boot; and this the more, that it would not have been thought possible to detect what, so to speak, disclosed itself. For the discovery was quite unconsciously made, being of the nature of a by-product to the outcome of another investigation. So systematically was his general search conducted that when the results came to be worked out it

appeared not only that he had seen an atmosphere, but actually measured it, although he was quite unaware of doing so at the time. The occasion was the measuring of the diameters of the planet, polar and equatorial. Micrometric measures of these were begun as early as the beginning of July, and kept up at intervals till the latter part of November. But the ones that proved specially tell-tale were those made from September 20th to November 22d, a set of polar and a set of equatorial ones having been taken throughout that interval on twenty-six nights.

Now, when these measures came to be worked out by me, corrected for all known sources of error and reduced to distance unity, a curious result made its appearance. As they stood arranged in their table chronologically, it was at once evident, even before taking the means, that, as time went on, something had affected the equatorial diameter which had not affected the polar one.

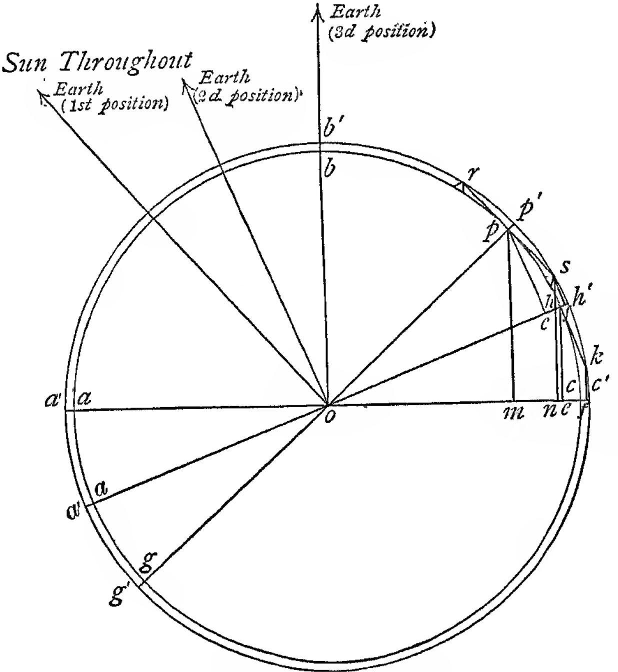
The values for the polar diameter were nearly the same from first to last. The equatorial values, on the other hand, showed, apparently, a systematic increase as the eye followed down the column. Something, therefore, had been at work on the one, which had not been at work on the other. Almost as instantaneously, it was evident what this something was, to wit,

a visible twilight unconsciously measured for a part of the planet's surface. Like the Down-easter who shingled fifty feet on to the fog, Mr. Douglass had measured several miles into the Martian air.

A word or two will explain this. The planet came to opposition on October 20. The mid-measures of the series, therefore, were taken within a few days of opposition, just before and just after that event. The subsequent ones, on the other hand, were made at a gradually increasing distance from this position, as the planet passed toward quadrature. Now, at opposition, the disk of the planet is full, like the full Moon; while, as it passes to quadrature, it loses something of itself, becoming gibbous, as the Moon does two or three days after the full. This loss from phase chiefly affects the equatorial diameter, the polar one remaining substantially unchanged by it. It would remain absolutely unchanged if the planet moved in the plane of the ecliptic. It does not so move, but the quantity resulting from lack of accordance is so small that for the present explanation it may be neglected. Now, this question of phase was the only point, practically, in which the equatorial and polar diameters differed during the interval under consideration. This, then, was the clew to the discrepancy.

It was not, however, the loss of phase that

was in question. That would have decreased the values of the equatorial diameter instead of increasing them, and, what is more immediately to the point, the correction for it had already been made. This correction is easily ascertained, for it depends chiefly upon the position of the planet in its orbit, which is known with great accuracy. The resulting values, therefore, had nothing to do with the phase correction as such, but they did, nevertheless, have to do with the phase itself.



To see exactly how this is possible, let us consider the effect an illuminated atmosphere would have upon the measurements in question. To make matters more obvious we will introduce a diagram. The inner circle represents a section of the planet in the plane of the ecliptic; the arrows, the directions in the same plane of the Sun and Earth from the centre of the planet, in the different positions to be considered; and the outer circle, an atmosphere surrounding the planet, at the limit at which it is dense enough to reflect light.

At opposition the Earth lay very nearly in the same line from the planet as the Sun. This is shown by the left-hand arrow. The illuminated semi-circumference of the planet's surface, at that time also the semi-circumference seen from the Earth, was *gabp*, and *gop* was the equatorial diameter; *g′a′b′p′* and *g′op′* the semi-circumference and equatorial diameter, upon the supposition of an atmospheric envelope encircling the surface. As the Earth and Mars passed along their orbits, the line from Mars to the Earth shifted into its second position, the Sun remaining as before. The illuminated part of the surface of Mars continued, therefore, to be *gabp;* but the portion of this illuminated surface visible from the Earth was only *dbp*, the part *gd* being invisible from the Earth, and the part *ph* lying in shadow. If, however,

there were an atmosphere capable of reflecting light up to a height represented by the greater circle, the Sun's rays would strike the upper visible limit of this atmosphere, not at p' but at s, sr being drawn parallel to the line from o to the Sun. The measured equatorial diameter, which is, of course, the projection of the arc $d'b's$ on the line $d'h'$, would be $d'f$ instead of de, which it would be were there no atmosphere. It thus appears that owing to side-lengthening, as we may perhaps style this reverse of foreshortening, the fringe of atmosphere increases in apparent width with increase of phase, to an apparent increase of the equatorial diameter.

If, now, we take a third position for the Earth where Mars shows a yet greater phase, the third arrow, we find that in this case the resulting apparent increase in the equatorial diameter is mn, and we notice that mn is greater than ef, just as ef was greater than pp' or cc'. That is, we see that the apparent increase in the size of the equatorial diameter varies directly, according to some law, with the increase in phase, or, as it is technically put, is a function of the phase.

This increase, being an increase in the measure itself, would in due course come in for its share of all the corrections applied to the diameter. In consequence, that diameter, instead of coming out simply the full equatorial diameter,

would come out too big in proportion to the amount added by the twilight arc.

Pursuant, therefore, to the supposition that such was the cause of the increase, I took the means of the polar and of the equatorial diameters with regard to the time from opposition, at which the measures were made, to find myself confronted by a series of values counterparting what we have just seen would be given by the presence of a visible twilight arc. The resulting values are: —

Polar Diameters:

October 15 to 23 inc.	9″.35
October 12 and 24 to 30 inc.	9″.35
November 2 to 21 inc.	9″.36

Equatorial Diameters:

October 15 to 23 inc.	9″.40
October 12 and 24 to 30 inc.	9″.43
November 2 to 21 inc.	9″.53

The measure of the 12th of October and those of the 24th to 30th are taken together, because equidistant from opposition on October 20.

The agreement of this table with that deducible by theory from the effect of an atmosphere is striking. But the agreement is even more exact than appears. For, as the polar axis was not in the same line as the axis of phase, the twilight arc to some extent affected the polar diameter at all times, but specially

during November. This becomes evident, numerically, on applying the correction for an atmosphere, which gives the following values:

Polar Diameters:

October 15 to 23 inc.	9″.32
October 12 and 24 to 30 inc.	9″.31
November 2 to 21 inc.	9″.32

Equatorial Diameters:

October 15 to 23 inc.	9″.37
October 12 and 24 to 30 inc.	9″.36
November 2 to 21 inc.	9″.37

The middle values are evidently somewhat too small, since they affect both the polar and equatorial diameters alike. Otherwise the variation in the values of the same diameter is less than the probable errors of observation. Taking the mean of all but the middle ones, we deduce the value for the polar flattening given above, $\frac{1}{190}$ of the equatorial diameter.

From the correction for the effect of the atmosphere, we find the amount of the twilight arc upon the planet visible from the Earth to be about 10°. That of the Earth, as seen from the Earth's surface, is 18°; but it is to be noticed that here the point of view is important. From the topmost layer of our air of sufficient density to be capable of reflecting light we are but forty miles away; from the corresponding layer of the Martian air we are forty millions of miles off. We cannot, therefore, expect to

detect the one to the same extent that we can the other. The value, then, for the Martian twilight arc of 10° is simply a minimal value, not an absolute one. The twilight arc cannot, from the observations, be less than this, but it may be much more.

The large number of measures from which the above means were deduced not only renders error in the result less likely, but shows that result to be due to air pure and simple. This appears from the fact that the observed increase is systematic. For its systematic character proves it due to something largely transparent. It is because it is chiefly not seen that it is seen at all. At first sight this deduction seems paradoxically surprising. But, in considering the problem, we shall realize that it must be so.

If what was seen were opaque, as, for example, a mountain, then in certain positions it would indeed be seen projecting beyond the terminator, — for example, if it were at *s* in the diagram on page 38; if, on the other hand, it were in the position *r*, it would, instead of apparently increasing, decrease the diameter. Now, as the rotation of the planet would bring it eventually into all possible positions, it would be as likely on any one occasion to be measured in a position to decrease the diameter as to increase it. From but a few measures, there-

fore, it might appear that there was an increase in the calculated diameter, or it might seem that there was a decrease from it, and either would be equally likely to happen. If, however, many measures were made, and just in proportion as they were many, those decreasing the diameter would offset those increasing it, and the mean of all would show no trace of either. In the mean the minus quantity would wipe out the plus. Indeed, owing to the fact that both the Sun and the Earth are not infinitely far off from Mars, and in consequence that all the lines to them are not strictly parallel to one another, the decreasing effect would actually slightly exceed the increasing effect, but this would be too small to be perceptible.

The same argument that applies to mountains applies to clouds, or to any opaque substance. Sporadic increase might be due to them; but for the increase to be systematic, it is necessary that the substance seen should also be seen through. It must be in part transparent. The measures, therefore, not only disclose the presence of an atmosphere, but do so directly.

Having thus seen first with the brain and then with the eye, and both in the simplest possible manner, that a Martian atmosphere exists, we will go on to consider what it may be like.

The first and most conspicuous of its characteristics is cloudlessness. A cloud is an event on Mars, a rare and unusual phenomenon, which should make it more fittingly appreciated there than Ruskin lamented was the case on Earth, for it is almost perpetually fine weather on our neighbor in space. From the day's beginning to its close, and from one end of the year to the other, nothing appears to veil the greater part of the planet's surface.

This would seem to be even more completely the case than has hitherto been supposed. We read sometimes in astronomical books and articles picturesque accounts of clouds and mists gathering over certain regions of the disk, hiding the coast-lines and continents from view, and then, some hours later, clearing off again. Very possibly this takes place, but not with the certainty imputed to it. It is also doubtful if certain effects of longer duration are really attributable to such cause. For closer study reveals another cause at work, as we shall see later, and the better our own air the more the Martian skies seem to clear. Certainly no instance of the blotting out of detail upon the surface of Mars has been seen this year at Flagstaff. Though the planet's face has been scanned there almost every night, from the last day of May to the end of November, not a single case of undoubted obscuration of any

part of the central portions of the planet, from any Martian cause, has been detected by any one of three observers. Certain peculiar brightish patches have from time to time been noted, but, with a courtesy uncommon in clouds, they have carefully refrained from obscuring in the slightest degree any feature the observer might be engaged in looking at.

The only certain dimming of detail upon the Martian disk has been along its bright semicircular edge or edges, as the case may be,— what is technically called its limb. Fringing this is a permanent lune of light that swamps all except the very darkest markings in its glare. This limb-light has commonly been taken as evidence of sunrise or sunset mists on Mars. But observations at Flagstaff during last June show that such cannot be the case. In June Mars was gibbous,—that is, he showed a face like the Moon between the quarter and the full,—and along his limb, then upon his own western side, lay the bright limb-light, stretching inward about thirty degrees. Since the face turned toward us was only in part illumined by the Sun, the centre of it did not stand at noon, but some hours later, and the middle of the limb consequently not at sunrise, but at about nine o'clock of a Martian morning. As the limb-light extended in from this thirty degrees, or two hours in time, the mist, if mist it was,

must have lasted till eleven o'clock in the day. Furthermore, it must have been mist of a singularly mathematical turn of mind, for it stretched from one pole to the other, quite oblivious of the fact that every hour from sunrise to sunset lay represented along the limb, including high noon. What is more, as the disk passed, in course of time, from the gibbous form to the full, and then to the gibbous form on the other side, the limb-light obligingly clung to the limb, regardless of everything except its geometric curve. But as it did so, the eleven o'clock meridian swung across it from one side of the disk to the other. As it passed the centre the regions there showed perfectly clear; not a trace of obscuration visible as it lay beneath the observer's eye.

From the first observation it is evident that Martian sunrise and sunset had nothing to do with the phenomenon, since it was not either Martian sunrise or sunset at the spot where it was seen; and, from both observations taken together, it is evident that the phenomenon did have to do with the position of the observer. For nothing on Mars had changed in the mean time, but only the point of view of the observer on Earth. It is clear, therefore, that it was not a case of Martian diurnal meteorological change, but a case of foreshortening of some sort.

To what, then, was the limb-light due? At

first sight, it would seem as if the Moon might help us; for the Moon's rim is similarly ringed by a lune of light. In her case the effect has been attributed to mountain slopes holding the Sun's light at angles beyond the possibility of plains. But Mars has few mountains worthy the name. His terminator — that is, the part of the disk which is just passing in or out of sunlight, and discloses mountains by the way in which they catch the coming light before the plains at their feet are illuminated — shows irregularities quite inferior to the lunar ones, proving that his elevations and depressions are relatively insignificant.

Not due, then, to either mountains or mist, there is something we know that would produce the effect we see, — dust or water particles in the Martian air; that is, just as the Earth's atmosphere is somewhat of a veil, so is the Martian one, and this veiling effect, though practically imperceptible in the centre of the disk, becomes noticeable as we pass from the centre to the edge, owing to the greater thickness of the stratum through which we look. At thirty degrees from the edge, our line of sight pierces twice as much of it as when we look plumb down upon the centre of the disk, and more yet as we approach the edge itself; in consequence, what would be diaphanous at the centre might well seem opaque toward the

limb. The effect we are familiar with on Earth in the haze that always borders the horizon,—a haze most noticeable in places where there is dust, or ice, or water in the air. Here, then, we have a hint of the state of things on Mars. Ice particles both are probable and would give the brilliancy required.

This first hint receives independent support from another Martian phenomenon. Contrary to what the distance of the planet from the Sun and the thinness of its atmospheric envelope would lead us to expect, the climate of Mars appears to be astonishingly mild. Whereas calculation from distance and atmospheric density would put its average temperature below freezing, thus relegating it to perpetual ice, the planet's surface features imply that the temperature is relatively high. Observation gives every evidence that the mean temperature must actually be above that of the Earth; for not only is there practically no sign of snow or ice outside the frigid zone at any time, but the polar snow-caps melt to a minimum quite beyond that of our own, affording rare chance for quixotic polar expeditions. Such pleasing amelioration of the climate must be accounted for, and aqueous vapor seems the most likely thing to do it; for aqueous vapor is quite specific as a planetary comforter, being the very best of blankets. It acts, indeed, like the glass

of a conservatory, letting the light-rays in and opposing the passage of the heat-rays out.

The state of things thus disclosed by observation, the cloudlessness and the rim of limb-light, turns out to agree in a most happy manner with what probability would lead us to expect; for the most natural supposition to make *à priori* about the Martian atmosphere is the following: When each planet was produced by fission from the parent nebula, we may suppose that it took with it as its birthright its proportion of chemical constituents; that is, that its amount of oxygen, nitrogen and so forth was proportional to its mass. Doubtless its place in the primal nebula would to a certain extent modify the ratio, just as the size of the planet would to a certain extent modify the relative amount of these elements that would thereupon enter into combination. Supposing, however, that the ratio of the free gases to the other elements remained substantially the same, we should have in the case of any two planets the same relative quantity of atmosphere. But the size of the planet would entirely alter the distribution of this air.

Three causes would all combine to rob the smaller planet of efficient covering, on the general principle that he that hath little shall have less.

In the first place, the smaller the planet the

greater would be its volume in proportion to its mass, because the materials of which it was composed, being subjected to less pressure owing to a lesser pull, would not be crowded so closely together. This is one reason why Mars should have a thinner atmosphere than our Earth.

Secondly, of two similar bodies, spheres or others, the smaller has the greater surface for its volume, since the one quantity is of two dimensions only, the other of three. An onion will give us a good instance of this. By stripping off layer after layer we reach eventually a last layer which is all surface, inclosing nothing. We may, if we please, observe something analogous in men, among whom the most superficial contain the least. In consequence of this principle, the atmosphere of the smaller body finds itself obliged to cover relatively more surface, which still further thins it out.

Lastly, gravity being less on the surface of the smaller body, the atmosphere is less compressed, and, being a gas, seizes that opportunity to spread out to a greater height, which renders it still less dense at the planet's surface.

Thus, for three reasons, Mars should have a thinner air at his surface than is found on the surface of the Earth.

Calculating the effect of the above causes numerically we find that on this *à priori* sup-

position Mars would have at his surface an atmosphere of about fourteen hundredths, or one seventh, of the density of our terrestrial one.

Observation supports this general supposition; for the cloudless character of the Martian skies is precisely what we should look for in a rare air. Clouds are congeries of globules of water or particles of ice buoyed up by the air about them. The smaller these are, the more easily are they buoyed up, because gravity, which tends to pull them down, acts upon their mass, while the resistance they offer varies as the surface they present to the air, and this is relatively greater in the smaller particles. The result is that the smaller particles can float in thinner air. We see the principle exemplified in our terrestrial clouds; the low nimbus being formed of comparatively large globules, while the high cirrus is made up of very minute particles. If we go yet higher, we reach a region incapable of supporting clouds of any kind, so rarefied is its air. This occurs about five miles above the Earth's surface; and yet even at this height the density of our air is greater than is the probable density of the air at the surface of Mars. We see, therefore, that the Martian atmosphere should from its rarity prove cloudless, just as we observe it to be.

So far in this our investigation of the Martian atmosphere we have been indebted solely to the

principles of mathematics and molar physics for help, and these have told us something about the probable quantity of that atmosphere, though silent as to its possible quality. On this latter point, however, molecular physics turns out to have something to say; for an Irish gentleman, Dr. G. Johnstone Stoney, has recently made an ingenious deduction from the kinetic theory of gases bearing upon the atmospheric envelope which any planet can retain. His deduction is as acute as it appears from observation to be in keeping with the facts. It is this: —

The molecular theory of gases supposes them to be made up of myriads of molecules in incessant motion. What a molecule may be nobody knows; some scientists supposing it to be a vortex ring in miniature, — something like the swirl made by a teaspoon drawn through a cup of tea. But, whatever it be, the idea of it accounts very creditably for the facts. The motion of the molecules is almost inconceivably swift as they dart hither and thither throughout the space occupied by the gas, and their speed differs for different gases. From the observed relations of the volumes and weights of gases to the pressures to which they are subjected is deduced the fact of this speed and its amount. It appears that the molecules of oxygen travel, on the average, at the rate of

fifteen miles a minute; and those of hydrogen, which are the fastest known, at the enormous speed of more than a mile a second. But this average velocity may, for any particular molecule, be increased by collisions with its neighbors. The maximum speed it may thus attain Clerk-Maxwell deduced from the doctrine of chances to be sevenfold the average. What may thus happen to one, must eventually happen to all. Sooner or later, on the doctrine of chances, each molecule of the gas is bound to attain this maximum velocity of its kind. When it is attained, the molecule of oxygen travels at the rate of one and eight tenths miles a second, the molecule of water vapor at the rate of two and one half miles a second, and the molecule of hydrogen at over seven miles a second, or four hundred and fifty times as fast as our fastest express train.

Now, if a body, whether it be a molecule or a cannon-ball, be projected away from the Earth's surface, the Earth will at once try to pull it down again: this instinctive holding on of Mother Earth to what she has we call gravity. In the cases with which we are personally familiar, her endeavor is eminently successful, what goes up coming down again. But even the Earth is not omnipotent. As the velocity with which the body is projected increases, longer and longer time is needed for

the Earth to overcome it and compel the body's return. Finally there would be reached a speed which the Earth would just be able to overcome if she took an infinite time about it. In that case the body would continue to travel away from her, at a constantly diminishing rate, but still at some rate, on and on into the depths of space, if there were no other bodies in the universe but the Earth and the molecule, till it attained infinity, at which point the truant would stop, and then reluctantly return. This velocity we may call the critical velocity. It is also known as the parabolic velocity, because it is at any point the velocity of a body moving in a parabola about the Earth, under the Earth's attraction; the parabola being the curve of a fall from infinity. The critical velocity is the parabolic velocity, inasmuch as gravity is able to destroy on the way up just the speed it is able to impart on the way down. But, now, if the body's departure were even hastier than this, the Earth would never be able wholly to annihilate its speed, and the body would travel out and out forever. If its speed at starting were less than twenty-seven miles a second, it would become thenceforth a satellite of the Sun; if its speed were yet greater, it would become an independent rover through space, paying brief visits only to star after star. In any case the Earth would know the vagabond no more.

As gravity depends upon mass, the larger the attracting planet the greater is its critical velocity, the velocity it can just control; and, reversely, the smaller the planet the less its restraining power. With the Earth the critical velocity is six and nine tenths miles a second. If any of us, therefore, could manage to acquire a speed greater than this, socially or otherwise, we could bid defiance to the whole Earth, and begin to voyage on our own account through space.[1]

This speed is actually attained, as we have seen, by the molecules of hydrogen. If, therefore, a molecule of free hydrogen were present at the surface of the Earth, and met with no other gas attractive enough to tie it down by uniting with it, the rover would, in course of time, attain a speed sufficient to allow it to bid good-by to Earth, and start on interspacial travels of its own. That it should reach its maximum speed is all that is essential to liberty, the direction of its motion being immaterial. To molecule after molecule would come this happy dispatch, till the Earth stood deprived of every atom of free hydrogen.

Now, it is a highly significant fact that there is no free hydrogen found in the Earth's atmosphere. There is plenty of it in the captivity of chemical combination, but none in the free

[1] See Appendix.

state. This coincidence of lack of hydrogen with lack of liberty takes on yet more significance from the further fact that the same is not true of oxygen, water vapor, or indeed of any of the other gases we know. With them, freedom is not synonymous with absence. The Earth's atmosphere contains plenty of free oxygen, nitrogen, and the like. But, as we have just seen,[1] the maximum speed of all these gases falls short of the possibility of escape. This accounts for their presence. They have stayed with us solely because they must.

The appearance of the other heavenly bodies seems to confirm this conclusion. The Moon, for example, possesses no atmosphere, and calculation shows that the velocity it can control falls short of the maximum of any of our atmospheric gases, that velocity being but one and one half miles a second. All were, therefore, at liberty to leave it, and all have promptly done so. On the other hand, the giant planets give evidence of very dense atmospheres. They have kept all they ever had.

But the most striking confirmation of the theory comes from the cusps of Venus and Mercury; for an atmosphere would prolong, by its refraction, the cusps of a crescent beyond their true limits. Length of cusp becomes, consequently, a criterion of the presence of an at-

[1] See Appendix.

mosphere. Now, in the appearance of their cusps there is a notable difference between Venus and Mercury. The cusps of Venus extend beyond the semi-circle; Mercury's do not. We see, therefore, that Mercury has apparently little or no atmospheric envelope, and we find that his critical velocity is only 2.2 miles per second, — below that of water vapor, and perilously near that of nitrogen and oxygen.

Turning to the case of Mars, we find with him the critical velocity to be three and one tenths miles a second. Now, curiously enough, this is, like the Earth's, below the maximum for the molecules of hydrogen, but also, like the Earth's, above that of any other gas; from which we have reason to suppose that, except for possible chemical combinations, his atmosphere is in quality not very unlike our own.

Having seen what the atmosphere of Mars is probably like, we may draw certain interesting inferences from it as to its capabilities for making life comfortable. The first consequence of it is that Mars is blissfully destitute of weather. Unlike New England, which has more than it can accommodate, Mars has none of the article. What takes its place there, as the staple topic of conversation for empty-headed folk, remains one of the Martian mysteries yet to be solved. What takes its place in fact is a perpetual serenity such as we can scarcely conceive of.

Although over what we shall later see to be the great continental deserts the air must at midday be highly rarefied, and cause vacuums into which the surrounding air must rush, the actual difference of gradient, owing to the initial thinness of the air, must be very slight. With a normal barometer of four and a half inches, a very great relative fall is a very slight actual one. In consequence, storms would be such mild-mannered things that, for objectionable purposes, they might as well not be. In the first place, there can be but little rain, or hail, or snow, for the particles would be likely to be deposited before they gained the dignity of such separate existence. Dew or frost would be the common precipitation on Mars. The polar snow-cap or ice-cap, therefore, is doubtless formed, not by the falling of snow, but by successive depositions of dew. Secondly, there would be about the Martian storms no very palpable wind. Though the gale might blow at fairly respectable rates, so flimsy is the substance moved that it might buffet a man unmercifully without reproach.

Another interesting result of the rarity of the air would be its effect upon the boiling-point of water. Reynault's experiments have shown that, in air at a density $\frac{14}{100}$ of our own, water would boil at about 127° Fahrenheit. This, then, would be the temperature at which

water would be converted into steam on Mars. So low a boiling-point would raise the relative amount of aqueous vapor held in suspension by the air at any temperature. At about 127° the air would be saturated, and even at lower temperatures much more of it would evaporate and load the surrounding air than happens at similar temperatures on Earth. Thus at the heels of similarity treads contrast.

We may now go on to some phenomena of the Martian atmosphere of a more specific character.

II. CLOUDS

Although no case of obscuration has been seen at Flagstaff this summer, certain parts of the planet's disk have appeared unaccountably bright at certain times. That these are not storm-clouds, like those which, by a wave-like process of generation, travel across the American continent, for example, is shown by the fact that they do not travel, but are local fixtures. Commonly, the same places appear bright continuously day after day and recurrently year after year, different astronomers at successive oppositions having so observed them. To this category belong the regions known as Elysium, Ophir, Memnonia, Eridania, and Tempe, which at certain seasons of the Martian year are phenomenally brilliant. They stay so for some time, and then the brightness fades out

to appear again at the next opposition. Still smaller bright spots, apparently more fugitive, have been seen this year by Professor W. H. Pickering, notably just north of the Mare Sirenum. None of the phenomena look distinctively like cloud. There are, however, phenomena that do.

Toward the end of August there were seen several times, first by Professor Pickering and then by me, strange flocculent collections of white patches, about fifteen degrees from the pole, in the place where the snow-cap had been, the cap itself having retreated farther south. In look they were unlike the snow-cap; and also unlike the land. But they did have very much the look of clouds. Possibly they were clouds, formed from the vapor left in the air by the melting of the cap. It was then but a few days to the summer solstice.

But the most marked instance of variability was detected in September last by Mr. Douglass in the western part of Elysium. On September 22 and 23 he found this blissfully bright region, as usual, equally bright throughout. But on September 24 he noticed that the western half of it had suddenly increased in brightness, and far outshone the eastern half, being almost as brilliant as the polar cap. When he looked at it again the next night, September 25, the effect of the night before

had vanished, the western half being now actually the darker of the two So fugitive an effect suggests cloud, forming presumably over high ground, and subsequently dissipating; it also suggests a deposition of frost, melting on the next day. It is specially noteworthy that the canals inclosing the region, the Galaxias, the Boreas, and the Eunostos, were not in any way obscured by the bright apparition. On the contrary, Mr. Douglass found them perceptibly darker than they had been, an effect attributable perhaps to contrast

Although not storm-clouds, it is possible that these appearances may have been due to thin cloud, capping high land. There are objections to this view, but as there are graver ones to any other it may stand provisionally, the more so that there are appearances not easily reconcilable with other cause. For example, a most singular phenomenon was seen by Mr Douglass on November 25, a bright detached projection, for which, from measurement, he deduced a height of thirty miles. This would seem to have been cloud, for the details of its changes in appearance seem quite incompatible with a mountainous character. With regard to its enormous height, it is not to be forgotten that a few years ago on the Earth phenomenal dust-clouds were observed as high as one hundred miles.

We now come to a highly interesting class of observations bearing upon the question of clouds, — Mr. Douglass's terminator observations. During the last opposition, seven hundred and thirty-six irregularities upon the terminator of the planet were detected at Flagstaff. They were seen by one or more of three observers, but chiefly by Mr. Douglass, who made a systematic scrutiny of the terminator for almost every degree of Martian longitude. Their full presentation would be both too tabular and too technical for this book. The paper embodying them will be found among the published annals of this observatory. I shall here give only certain deductions from it.

Of the 736 irregularities observed, 694 were not only recorded but measured. Of these 403 were depressions. It is singular, in view of their easy visibility, that they never should have been noticed before. Schroeter, indeed, saw three appearances of the sort, — on September 21, 1798, November 12, 1800, and December 18, 1802, — but all on the limb, not the terminator, which shows them not to have been of those here meant. Nevertheless they are not difficult to see, and anything but rare. When the phase is large enough, several may be seen every night.

The projections number 291. As their number shows, they are less common than the depressions, but they are even less of a feature of

the surface than their number would indicate, for the depressions extend as a rule much further both in latitude and longitude.

Usually the depressions look like parings from the planet's rind, and almost always appear upon that part of the terminator where the dark regions are passing out of sight; commonly therefore, in the case of the southern hemisphere, they are met with between latitudes 30° to 60° south. Not so common is it for them to occur over a part of the planet which is bright. Furthermore, they appear to occur more or less continuously. This would not be the case were they real depressions.

As this may not at once be evident to the reader, and yet is easily made evident, we will consider the diagram on page 38. It will there be seen that an elevation like *s* or *r* — and the same reasoning applies *mutatis mutandis* to a depression — appears projected a relatively long way without or within the terminator, as compared with its actual length, owing to the angles under which it is respectively illuminated by the Sun and seen from the Earth. The relation between its height and its distance from the edge is that between the height of a hill and the shadow it casts at sunrise or sunset. What, therefore, is not high enough to be seen in profile on the limb, becomes vicariously visible on the terminator. But a hill could not continue

long to appear as an elevation, as the rotation of the planet would carry it in due course from the position r to the position s, and there it would be forced to masquerade as a depression. The same, reversely, would happen to a valley. In order that a depression should appear continuously, there must be a belt of lower level along its circle, and this could not be made visible as in the former case by projection, since projection depends upon difference of level along the same surface contour, not as between adjacent ones. It could, therefore, only be noted by its actual profile, — a very small affair, still further diminished by reason of the angle under which that profile was viewed. The resulting quantity in the case of Mars would be exceedingly minute. We perceive therefore, on the very threshold of our inquiry, reason to doubt the mountainous character of the irregularities. Such inference becomes the more probable on a more detailed investigation, into which we will now enter. This investigation depends upon a very important principle; namely, that if we have, as in this case, a great number of observations, it is possible, by dividing them into classes according to their kind and then taking the mean value of each class, to discover characteristics not otherwise exposed.

Means are very telling things. They are so from the fact of simplifying the effects of the

factors at work. By taking the average of the series of observed values according to some definite principle, not only do we eliminate a very large class of errors, but we allow by so doing the various causes to unmask their separate results. The importance of reasoning upon averages could hardly be more strikingly exemplified than in the very case before us,—that of these depressions and projections seen on the terminator of Mars.

Of the 694 irregularities measured, 291 were projections and 403 were depressions. Here at the very outset, then, we perceive an objection to the theory that they are due to mountains; to wit, because the number of depressions so greatly exceeds the number of projections. As previously explained on page 64, mountains would produce on the average as many projections as depressions, for they would project the light on the one side as much as they would cut it off on the other.

Now let us classify these irregularities, and see if we can gain further information about them. There were two kinds of them,—the long and low, and the short and sharp. Each kind had its representatives among both the projections and the depressions. Of the short and sharp variety there were 95 projections. These averaged 0.276 seconds of arc in height. Of the same kind there were similarly 57 depres-

sions which averaged 0.368 seconds of arc in depth. It will be noticed then, first, that the projections of this character exceeded in number the depressions of the same; secondly, that the average depth of the depressions exceeded the average height of the projections. Now, if the appearances had been due to mountains, both the number and size of the projections and of the depressions should have been substantially the same. They were emphatically neither. Consequently mountains fail to explain them. But there is another possible set of phenomena that will; namely, clouds. For, in the first place, clouds would cause apparent depressions and projections, since the light would linger on them as it does on mountain tops, and they would cast shadows as mountains do. But furthermore their two effects, of extending or curtailing the limit of vision along the terminator, would not necessarily be equal, as would be the case with hills. Because it is a peculiarity of mountains that they are attached to the soil, and are commonly permanencies; while clouds are not. The latter form and dissipate, dissipate and re-form, and their metamorphoses are phenomena depending upon the time of day. Consequently they may appear in one place at one time, in another the next; and what is no less important, they may form at different heights at different times. They therefore not

only account for irregularities on the terminator, but they account also for irregularity in the plus or minus character of these irregularities. Clouds, therefore, are capable of explaining the case before us, although mountains are not.

From what we have just shown let us mark now just what clouds are here required to account for what we see. The clouds that cause depressions are those within the terminator,—those, that is, that form before sunset or after sunrise; while those that cause projections are those that gather after sunset or before sunrise. As the observed projections in this case exceed the depressions in number, we infer, then, that there are more clouds after nightfall than before it, and similarly more before daybreak than after it; next, as the average depression is greater than the average projection, we likewise infer that the day clouds lie at a higher altitude. Now, this is precisely what we should expect would be the case, just as it is the case on the Earth.

Of the other class of irregularities, the long and low, there were observed 196 projections and 346 depressions. The projections averaged 0″.136 in height; the depressions, 0″.125 in depth. Here, then, we have an opposite state of things from that with which we were confronted in the short and sharp class. Here, as compared with the projections, instead of relatively few

depressions of greater height, we have relatively many depressions of less height. Furthermore, there are a great many more of both projections and depressions than there were of the former variety, and they are both of much less height or depth. Evidently, therefore, we have here, in part at least, a different class of phenomena from what we have previously considered. Now we perceive at once that two factors enter here which did not enter in the case of the short and sharp irregularities. The long and low depressions occur, as we shall recall, almost always over the dark areas, while the short and sharp ones do not. In the next place, the average height or depth of the long and low irregularities is much nearer the value of the irradiation constant, that is, the amount by which a bright object seems bigger on account of its brightness; which would cause the dark areas to seem depressed. From these facts we infer that most of the depressions of this class are due to the character, not to the contour, of the surface where they occur, partly to the direct effect of lack of irradiation, partly to sombreness of the surface, which would cause the light to fade from them at a greater relative distance from the terminator. On eliminating these depressions, therefore, we find ourselves left with very few depressions as against nearly 200 projections. The excess in number of the

latter shows, as in the case of the other variety, that we are here dealing chiefly with long and relatively low clouds formed after sunset or before sunrise; those so formed during daylight being few if any.

One more observation made at Flagstaff, on the subject of cloud, is as peculiar as it is important. It was made by Mr. Douglass, and I shall give it in his own words. A more detailed account of it, together with his tables of figures, will appear in his paper upon it in the Observatory annals: —

"On November 25 and 26 a bright spot was seen in the unilluminated portion of Mars, to which, in my opinion, no other name than cloud can be applied. Its great height, size, and brilliancy, and, on the second evening, its singular fluctuations, render it of importance in the study of the Martian atmosphere.

"I first saw it at 16h. 35m., G. M. T., of November 25, and made an estimate of its height. It seemed to be rapidly increasing in length in a direction parallel to the terminator at that point. Subsequent estimates of its height gave a different and greater value than at first, until its sudden disappearance at 17h. 6m., or perhaps a minute later. After once attaining its size, it seemed to remain with little change, presenting the appearance of a line 115 miles long by 33 miles wide at the centre and lying parallel to

the terminator, but separated from it by an apparent space of over 80 miles. It was generally yellowish in color, like the limb, but of less brilliancy than the centre of the disk, though distinctly surpassing in that respect the adjacent terminator. I estimated it to have the brillianey of the bright areas of the disk at a distance of 9° from the terminator. In one view it appeared to be a very small whitish point, and I am inelined to think that there may have been a real diminution in its size at that moment. This idea is partly sustained by the following night's observations. At 16h. 54m. it was observed by Professor Piekering, whose estimate gave 11 miles for its height. At 17h. 5m., after obtaining two readings of the micrometer screw for latitude, the seeing, whieh had been quite steadily at the figure 7 (on a seale of 10), dropped to 4, and in attempting the next setting I eould not find the 'cloud,' although onee before it had remained visible when the seeing dropped instantaneously to that figure. Nor did it reappear in the next half hour. This sudden disappearanee, without any previous lessening of its height above the terminator or of its size, made its cloud eharaeter unmistakable, since a mountain beyond the sunrise terminator must either constantly decrease in height, or soon join the illuminated disk.

"A subsequent computation showed that this phenomenon took place over the southern part of Schiaparelli's Protei Regio. Other reasons lead me to think, however, that he has placed that island some 5° too far south.

"On November 26 the cloud promptly appeared at 17h. 15m., G. M. T., but about 12° farther north. Instead of remaining continuously visible, it dissipated and reformed at irregular intervals. The first appearance lasted sixteen minutes. After somewhat over four minutes had passed, it reappeared momentarily, and six minutes elapsed before it appeared again, lasting then but two and one half minutes. Then followed an absence of three minutes, presence for two minutes, absence for three minutes, presence for one minute, and a final brief appearance eight minutes later at 18h. 1m. Its presence was suspected five minutes before that hour, and again at 18h. 11m., but with great uncertainty.

"At this time it presented in general the same characteristics as the night before, though its appearances were too brief to permit such careful observations as were hoped for. The seeing, too, was not so good as before, varying from 4 to 7; and if the cloud happened to appear under the former figure, its observation was difficult. It is needless to remark that under such conditions it was impossible to ob-

serve its appearance or disappearance to the second. In general, it seemed to exhibit a less elevation than the night before. A careful estimate of its latitude placed it precisely at the centre of the terminator. I believe these latitude observations, though made rapidly, cannot be subject to an error greater than 2°, and probably less than 1°. On November 27, at 18h., I searched for the cloud, but was not rewarded by finding any trace of it.

"Estimates of the size and height of this cloud were made with reference to a glass thread in the micrometer, whose diameter is 0″.6. One tenth of the thread was found to represent on Mars a little less than twenty miles. This gives us an elevation above the surface of between 10 and 11 miles. In this process we have taken the apparent centre of the cloud, and have assumed the seeing to have no influence. We obtain, therefore, the smallest possible mean height of the centre of the cloud. If we assume that the seeing was not perfect, its effect would be to lessen the separation, but not to change the total height. Supposing, for example, that the apparent extension of the cloud was due to poor seeing enlarging a point, then our terminator distance would be 245 miles, and our minimum elevation 15 miles. Therefore we can assume 15 miles to be the smallest probable mean elevation of this cloud. The

average height of our cirrus clouds is five and one half miles.

"One more idea requires mention, namely, the movement of this cloud in latitude. From the extreme rarity of clouds on Mars I am inclined to connect intimately the appearances of the two evenings, and consider them as due to one source, presumably a large body of air moving northward. Such an advance would be at the rate of 18.7 miles per hour."

I may add to this that the height of the cloud — relatively to those of the Earth — is what direct deduction from the less rapid thinning out of the air above the Martian surface, which must result from the smaller mass of Mars, would lead us to expect. The air at the surface would be thinner than at the surface of the Earth, but the rate at which it diminished with the height above that surface would not be so great. At no very great elevation the two densities would come to be the same.

One deduction from this thin air we must be careful not to make — that because it is thin it is incapable of supporting intelligent life. That beings constituted physically as we are would find it a most uncomfortable habitat is pretty certain. But lungs are not wedded to logic, as public speeches show, and there is nothing in the world or beyond it to prevent, so far as we know, a being with gills, for example,

from being a most superior person. A fish doubtless imagines life out of water to be impossible; and similarly to argue that life of an order as high as our own, or higher, is impossible because of less air to breathe than that to which we are locally accustomed, is, as Flammarion happily expresses it, to argue, not as a philosopher, but as a fish.

To sum up, now, what we know about the atmosphere of Mars: we have proof positive that Mars has an atmosphere; we have reason to believe this atmosphere to be very thin, — thinner at least by half than the air upon the summit of the Himalayas, — and in constitution not to differ greatly from our own.

III

WATER

I. THE POLAR CAP

After air, water. If Mars be capable of supporting life, there must be water upon his surface; for, to all forms of life, water is as vital a matter as air. On the question of habitability, therefore, it becomes all-important to know whether there be water on Mars.

To the solution of this inquiry, also, the planet's polar cap turns out to hold the key. For just as the fact of change in the cap proves the presence of air, so the manner of that change implies the presence of water. It not only does this; it turns out to do a deal more. For to the whole water question it appears to play the part not only of occasion but of cause. In more senses than one, it is in that great glistening white patch that our water problem takes its rise.

On the 3d of June, 1894, the south polar cap stretched, almost one unbroken waste of white, over about 55 degrees of latitude. A degree on Mars measures 37 miles; consequently the

cap was 2,035 miles across. Inasmuch as the inclination of the Martian equator to the plane of the Martian orbit is, according to Schiaparelli, 24° 52′, it must have then covered more than the whole south frigid zone of the planet.

Now, to take in the full meaning of the condition of the cap at this time and of the changes that ensued, we must begin by determining the Martian time of year. This is done by fixing the dates at which the Martian pole reached its maximum tilt toward or from the Sun, and the dates at which it was not tilted either to or from, but sideways to, the Sun; the former gives us the Martian solstices, and the latter the Martian equinoxes. It thus appears that on April 7, 1894, occurred the vernal equinox of the Martian southern hemisphere, on August 31, its summer solstice, and on February 7, 1895, its autumnal equinox. From these dates it is easy to transform the one calendar into the other. On the 3d of June, 1894, therefore, it was about May 1 on the southern hemisphere of Mars.

On May 1, then, Martian time, the cap was already in rapid process of melting; and the speed with which it proceeded to dwindle showed that hundreds of square miles of it were disappearing daily. As it melted, a dark band appeared surrounding it on all sides. Except, as I have since learned, at Arequipa, this band has

never, I believe, been distinctively noted or commented on before, which is singular, considering how conspicuous it was at Flagstaff. It is specially remarkable that it should never have been remarked upon elsewhere, in that a similar one girdling the north polar cap was seen by Beer and Mädler as far back as 1830. For it is, as we shall shortly see, a most significant phenomenon. In the first place, it was the darkest marking upon the disk, and was of a blue color. It was of different widths at different longitudes, and was especially pronounced in tint where it was widest, notably in two spots where it expanded into great bays, one in longitude 270° and one in longitude 330°. The former of these was very striking for its color, a deep blue, like some other-world grotto of Capri. The band was bounded on the north, that is, on the side toward the equator, by the bluish-green areas of the disk. It was contrasted with these both in tone and tint. It was both darker and more blue.

The band not only varied in width at different longitudes, but its width corresponded to the amount of the blue-green areas of the disk visible at these longitudes below it. It was widest where these were greatest in extent, and narrowest where they were least. If we consult the map of Mars we shall see that below the bay in longitude 330° lies the great dark

area, the Syrtis Major, and, below the one in longitude 270°, the Syrtis Minor. This correlation was highly suggestive in itself. As if, however, to remove all question as to possible coincidence having a hand in the matter, the agreement in position was emphasized by visible connection. Two long dark streaks appeared joining respectively each bay to its corresponding Syrtis.

But the most significant fact about the band was that it kept pace with the polar cap's retreat toward the pole. As the white cap shrank it followed *pari passu* so as always to border the edge of the snow. It thus showed itself not to be a permanent marking of the planet's surface, since it changed its place, but a temporary one, dependent directly upon the waning of the cap itself. In short, it was an associated detail, and itself instantly suggested its character, namely, that it was water at the edge of the cap due to the melting of the polar snow.

Not only did the band conform with the cap in position; it did so in size. As the snows dwindled, the blue band about them shrank in width to correspond. By August it was a barely discernible thread drawn round the tiny white patch which was all that remained of the enormous snow-fields of some months before. Finally, on October 13, when the snow entirely disappeared, as we shall presently see, the spot

where it and its girdle, long since grown too small for detection, had been became one yellow stretch.

That the blue was water at the edge of the melting snow seems unquestionable. That it was the color of water; that it so persistently bordered the melting snow; and that it subsequently vanished, are three facts mutually confirmatory to this deduction. But a fourth bit of proof, due to the ingenuity of Professor W. H. Pickering, adds its weight to the other three. For he made the polariscope tell the same tale. On scrutinizing the great bay through an Arago polariscope, he found the light coming from the bay to be polarized. Now, to polarize the light it reflects is a property, as we know, of a smooth surface such as that of water is.

Before going further we will take up here at the outset the question of the constitution of these polar caps, which in their general behavior so strikingly suggest our own ice-caps as they would appear could they be seen from a distance of forty millions of miles. That they so instantly suggest snow has suggested, to that class of mind which likes to make of molehills of question mountains of doubt, the possibility that instead of ice we have here snow-caps of solid carbonic acid gas (carbon dioxide). The occasion of the suggestion is the fact that carbonic dioxide under certain conditions becomes

a colorless liquid, and then a solid of a floccular, snow-like character. It assumes, in short, under proper conditions of pressure and cold, the various appearances presented by water under higher temperatures, although it does so with very different degrees of ease. Superficially, therefore, the idea seems plausible. Let us see if it still seems so when critically examined.

Faraday made experiments on the relation of the congealing point of carbonic acid gas to the pressure, and found that at 0° C. it took a pressure of 36 atmospheres, that is, 540 pounds to the square inch, to solidify the gas, and that at —99° C., the lowest temperature with which he experimented, it took 1.14 atmospheres. At this point the curve representing the relation was becoming apparently asymptotic, that is, a slight decrease in pressure involved a great falling off of temperature. Under a pressure of one atmosphere, therefore, the temperature would be about —170° F., that is, on the surface of the Earth this would be the congealing point of the gas.

He found further that the curve for the liquefaction point lay very close to that for the congealing point, and approached yet closer as the pressure decreased. In other words, the gas passed almost immediately from the gaseous to the solid state.

In the light of these facts let us consider the

condition of Mars. Three points arise which we will take in the inverse order of their importance. First: the appearance of the planet shows conclusively that, if the polar caps be composed of solid carbonic acid gas, then either there is no water at all on Mars in any form whatsoever, or what there is is ice so overlaid with detritus as to be invisible. For if the two substances were there together, and the cold at the surface of the planet of so extreme a character as to congeal the carbon dioxide, the water must *a fortiori* be frozen, and would continue so long after the temperature rose above the melting point of the former substance. We should therefore still have snow-fields of snow after the melting of those formed of carbonic acid gas, either visible as white patches or so covered up with dirt as to pass for land. Now there are no such additional white patches to be seen, nor, so far as we can judge, does any part of the planet behave as if it were glacier-bound.

Second: carbonic dioxide passes, as we saw, almost simultaneously into the liquid and solid states, especially under slight pressure. Now, the pressure is certainly very slight on the surface of Mars; not probably more than, and probably less than, one seventh of an atmosphere. In consequence, on a rise of temperature the frozen carbonic acid gas would there pass practically straight from the solid into the gaseous

state. Now, from the existence of the surrounding polar sea, we remark that in the substance composing the polar caps of Mars this does not occur. A considerable portion of it is always in the transition state of a liquid. Carbonic dioxide would not thus tarry: water would.

Third: from the curve of metamorphosis, it is evident that the temperature necessary to freeze the gas under the pressure of one seventh of an atmosphere must lie between —100° C. and —200° C., if not lower. —200° C. is, so far as we can judge, about the temperature of interplanetary space, or what would be the temperature of the night side of Mars were the planet destitute of atmosphere. But there is an atmosphere on Mars, and, even if there were not, on melting the carbonic dioxide would itself make an atmosphere. This would instantly raise the temperature, and under any rise in temperature the congealing of the gas at once becomes an impossibility. The gas itself thus suggests its own refutation.

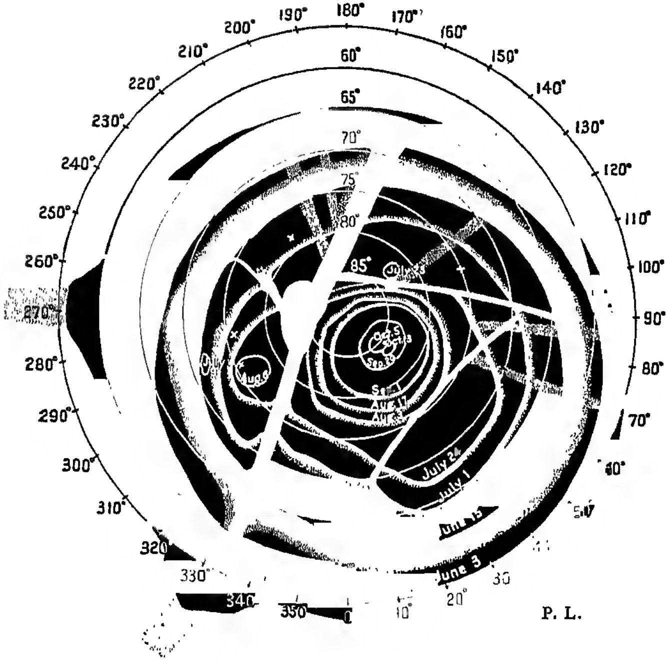
There is no such apparent objection to water. With an atmosphere properly constituted (and there is nothing to show that the Martian atmosphere is not so constituted), the temperature might easily rise high enough to melt ice. We may therefore conclude water to be the most probable solution of the question.

With such more or less solid ground to

stand on, we may now go on to describe the behavior of the cap as constituted of snow. Whether we call it snow-cap or ice-cap is immaterial, as, although it would probably be deposited as hoar-frost rather than as snow in the first instance, owing to the thinness of the Martian air, the latter end of either form of the substance would be much the same, — glacier-ice.

It will be interesting to examine more in detail the annual history of the ice-cap, especially as this history was unrolled before us last year more minutely than has been the case for the last fifteen years, and than will be the case for fifteen years to come. This was due not only to the relative proximity of the planet during the last opposition, but to the further fact that its south pole was tilted toward us at a maximum angle. The vicissitudes which the polar cap underwent stood, in consequence, remarkably well displayed. To such advantage were they seen that it has been possible to construct a map of the Martian south circumpolar regions to a degree of detail such as has never been possible before, and which I have accordingly done. It will be seen from it (on the opposite page) how much farther advanced is our knowledge of the Martian south pole, and the regions about it, than is our knowledge of either of our own. It is also pleasing to re-

PLATE II



MAP OF THE SOUTH POLE OF MARS
SHOWING THE POLAR CAP AND ITS CHANGES IN 1894

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

member that during this our polar expedition we were not frost-bitten for life, nor did we have to be rescued by a search party. We lived not unlike civilized beings during it all, and we actually brought back some of the information we went out to acquire.

On examining the chart in which the successive appearances of the southern ice-cap are depicted at different times, from June 3 to October 13, or, in terms of the Martian time of year, from May 1 to July 15, the first point to strike one is that the cap was during its whole existence eccentrically placed with regard to the geographical pole of the planet. In other words, the pole of rotation and the pole of cold did not coincide. The latter lay on the average some six degrees distant from the former. This shows that the isotherms in the southern hemisphere of Mars do not coincide with the parallels of latitude.

The manner of the cap's melting further shows that differences of level exist in it. For, in addition to melting round its edge, the cap proceeded to melt asymmetrically. On the first night that Professor W. H. Pickering observed it, on May 22, with the six-inch telescope, he suspected a rift crossing the cap from longitude 330° to longitude 170°. This rift grew more and more evident, until, in the early part of June, it was unmistakable. It grew in visibility chiefly from actual growth in size. On June 6

it was estimated, on a scale of ruled lines made for the purpose, to be about 100 miles wide. On June 15 it was similarly found to measure 220 miles.

Meanwhile an interesting phenomenon occurred in the cap on June 7. On that morning, at about a quarter of six (or, more precisely, on June 8, 1h. 17m., G. M. T.), as I was watching the planet, I saw suddenly two points like stars flash out in the midst of the polar cap. Dazzlingly bright upon the duller white background of the snow, these stars shone for a few moments and then slowly disappeared. The seeing at the time was very good. It is at once evident what the other-world apparitions were,—not the fabled signal-lights of Martian folk, but the glint of ice-slopes flashing for a moment earthward as the rotation of the planet turned the slope to the proper angle; just as, in sailing by some glass-windowed house near set of sun, you shall for a moment or two catch a dazzling glint of glory from its panes, which then vanishes as it came. But though no intelligence lay behind the action of these lights, they were none the less startling for being Nature's own flash-lights across one hundred millions of miles of space. It had taken them nine minutes to make the journey; nine minutes before they reached Earth they had ceased to be on Mars, and, after their travel of

one hundred millions of miles, found to note them but one watcher, alone on a hill-top with the dawn.

Calculation showed the position of the star-points to be in longitude 280° and 290° and in latitude 76° south. At this place on the planet, then, there was a range of slopes sufficiently tilted to reflect the Sun from their ice-clad sides. On comparing its position with Green's map of his observations upon the cap at Madeira in 1877, it appeared that this was the identical position of the spot where he had seen star-points then, and where Mitchell had seen them in 1846, to whom they had suggested the same conclusion. Green christened them the "Mitchell Mountains." At the times both these observers saw them, they were detached from the rest of the cap. At the time of this observation in June, they were still in the midst of the cap. We shall see that they eventually became islands, just as Green saw them, and that the observation in June marked an earlier stage in their history.

On June 10 Mr. Douglass detected a second rift in the cap backing the range of slopes. And on June 13 I noticed that behind the bright points the snow fell off shaded to this rift. Meanwhile a third rift had been made out by him, running from longitude 170° to longitude 90°, — very nearly, therefore, at right

angles to the first rift and debouching into it. Bright points continued to be seen at various points to the westward round the cap. They are marked by crosses on the chart. Throughout these days, the cap was wont to appear shaded upon the terminator side, as one might expect of a snow or ice slope. During June, also, the contour of the cap was apparently elliptical. But on June 25 Professor W. H. Pickering noted, for the first time, that it no longer looked so. The melting had resulted in making its asymmetry perceptible.

On July 1 our Martian polar expedition disclosed what used to be the supreme quest of earthly expeditions, — that dream of arctic explorers, an open polar sea. On that day Professor Pickering perceived, in the midst of the cap, in longitude 260° and latitude 80°, a sheet of water about 250 miles long by 150 broad. It was in fact the spreading of the first rift about midway across the cap, and lay not far from the geographical pole of the planet, though not, it is to be noticed, near the pole of cold, for it lay on the further side of the geographical pole from it. There is a touch of the irony of fate in this detection of an open polar sea on Mars before explorers have succeeded in doing so on the Earth.

In addition to these rifts and other irregularities of melting, small detached bits of the

cap showed from time to time, one being seen by Professor Pickering on July 9 in longitude 284°, and another by him on July 23 in about longitude 160°.

Meanwhile the cap had been steadily decreasing in size, its progressive diminutions being shown on the map in the successive contour lines. The polar sea faithfully followed it in its shrinkage, even the bays keeping their longitudes unchanged. But, whereas early in June the bay at longitude 270° had been blue, it now appeared brown; of that mud-color land does from which the water has recently been drained off.

After various vicissitudes, too numerous to mention in detail, on August 6 a separate patch of snow showed very conspicuous, to the left of the main body. The smaller detachment lay in longitude 290°, and in latitude 75°–78°. Now, on turning to the record of the star-points that had appeared two months before, it will be seen that this was their position. Here, then, was proof of the identity of the star-points seen in June with the islands recorded by Mitchell and Green. The detached patch was in fact the range of slopes left in isolated insularity after all about it had melted away. From this we have an interesting bit of corroborative testimony that it stood on higher ground.

On August 11 the detached patch was yet

farther separated from the main body of the cap, the smaller patch being many degrees distant to the north of either the geographical pole or the pole of cold, with water and even dry land to the south of it. It will be remembered, for the points of the compass, that this is the southern hemisphere of which we are speaking, and that, for climatic purposes, north and south here stand interchanged. On August 13 the detached patch is recorded for the last time, or, in other words, about this time it melted away. The larger one remained, contracting in size, however, as time went on. So it continued through August, September, and well into October.

On October 12, at 10h. 40m., I made the following entry about it: "Polar cap has been very faint for some time; barely visible." At 13h. 26m., or, in other words, at about half past one that night, Mr. Douglass measured its position and estimated its size, as was his wont every few days. He found it to be six degrees distant from the planet's pole, in longitude 54°. The patch was very small, covering about one hundred and fifty miles square. On looking at the planet on October 13, at 8h. 15m., to his surprise he found the cap gone. Not a trace of it could be seen; nor could either he or I detect it during the rest of that night, although such was the longitude of the central

meridian throughout it as to bring the cap on the nearer side of the pole, and therefore show it to best advantage. What had certainly been there on the 12th was not there on the 13th. The ice-cap had disappeared.

No such occurrence has ever been chronicled before. It is the first time since man began to observe the planet that the ice-cap has completely disappeared. Hitherto it has been seen to diminish to a minimum of from 7° to 4°, and then begin to increase again. This last autumn, for the first time, it vanished entirely. The date of this occurrence was, in Martian chronology, about July 20. Evidently, for some reason unknown to us, it was a phenomenally hot season in the southern hemisphere of the planet.

Practically it never reappeared again during the season. That it did return occasionally, as a very small speck, was from time to time suspected, and doubtless did take place. Certainly it left for some time behind it a glimmer where it had been, due presumably to the moisture from its melting, still tarrying on the ground or lingering in the air. Otherwise, to all intents and purposes, where the polar ice-cap and polar sea had been was now one ochre stretch of desert.

Having thus followed to its vanishing point the polar cap, we will now return to it in the

heyday of its youth, in June, 1894, when it was girdled by its broad blue belt. We have seen that we have reason to believe this to be in all probability a polar sea, a real body of water. There is, therefore, water on the surface of Mars. We also mark that this body of water is ephemeral. It exists while the icecap is melting, and then it somehow vanishes. What becomes of it, and whether there be other bodies of water on the planet, either permanent or temporary, we will now go on to inquire.

II. AREOGRAPHY

As in the course of our inquiry we shall have occasion to refer familiarly to different Martian features, we had best begin it with some slight exposition of Martian geography, or of areography, as it may by analogy be called. To get this we will, by the help of Plates III. to XIV., suppose ourselves to be viewing the planet from some standpoint in space, and watching the surface features pass in procession under our gaze as the rotation of the planet brings them successively round into view. In the matter of names the map of the planet toward the end of the book, with its accompanying index, will give identification. We may thus make a far journey without leaving home, and from the depths of our arm-chairs travel in spirit to lands we have no hope of ever reaching in body.

We may add to this the natural delight of the explorer, for we shall be gazing upon details of Martian geography never till last summer seen by man.

Areography is a true geography, as real as our own. Quite unlike the markings upon Jupiter or Saturn, where all we see is cloud, in the markings on Mars we gaze upon the actual surface features of the Martian globe. That we do so we know from the permanency of the spots and patches thus revealed to us. They change in appearance, indeed, according to times and seasons, but they alter as true surface features would, not like cloud-belts that gather to-day and vanish forever to-morrow. That the markings are essentially permanent has been known ever since Cassini in 1666 definitely discovered, what Huyghens had thought to detect in 1659, the rotation of the planet, by means of their periodic presentations.

The twelve views we shall here scan are of the nature of a map, made in November, 1894. They represent the *ensemble* of the drawings from this observatory, for about that date. The details from these drawings were plotted upon a globe, which was then tilted toward the observer at the angle at which the Martian south pole itself was tilted toward the Earth during November, and photographed at intervals of 30°. The negatives were then made to

conform as near as might be to the actual look of the planet. To photograph minute planetary markings directly is, for reasons too long to state here, impossible. The views give between them the whole surface of the planet shown us at what corresponds to our first of August. Thus, neither the polar cap nor the polar sea appear in the pictures, for both had then disappeared. Nor do the southern parts of the so-called straits show, for a similar reason. But from a knowledge of the features here presented the reader will find interpolation of any others referred to easy.

Previous to the present chart, the most detailed map of the planet was Schiaparelli's, made in 1888. On comparison with his, it will be seen that the present one substantially confirms all his detail, and adds to it about as much more. I have adopted his nomenclature, and in the naming of the newly found features have selected names conformable to his scheme, which commends itself both on practical and on poetic grounds.

We will begin our journey at the origin of Martian longitudes and travel west, taking the points of the compass as they would appear were we standing upon the planet. As all astronomical pictures are, for optical reasons, upside down, south lies at the top of the pictures, west to the right, north at the bottom,

and east to the left. Mars rotates as the Earth does, from west to east, so that day as it advances across the face of the planet follows the order here shown in Plates III. to XIV., the order in which we shall observe them. Places on the right of the picture are in the morning of their Martian day; places on the left, in its afternoon. To facilitate reference by longitude and latitude, the globe has been belted by meridians and parallels each 10° apart, and the meridians have been numbered along the equator. This premised, we will suppose ourselves to be standing on the equator at its intersection with the 0° meridian. (Plate III.)

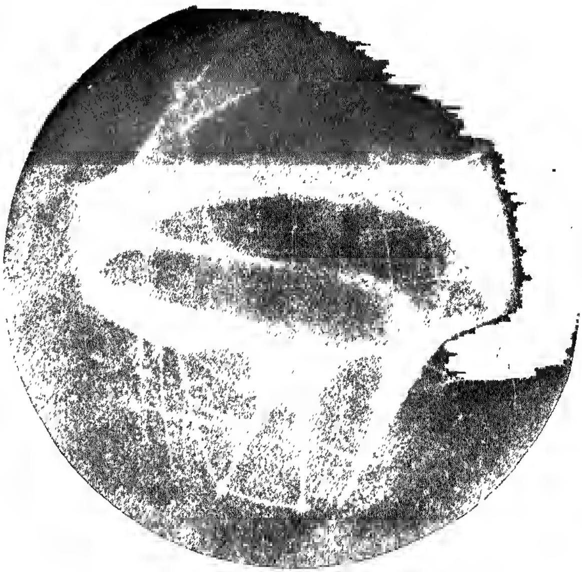
It will be noticed that the 0° meridian passes through the tip of a triangular peninsula that juts out into a dark area curiously forked, half way across the picture and about two thirds way down it. The tip of this triangle is the received Greenwich of Martian longitudes, and has been named by Schiaparelli the Fastigium Aryn, such having been the name of a mythologic spot supposed by the ancients to lie midway between the east and west, the north and south, the zenith and nadir. It thus makes a fitting name for the starting-point of Martian longitudes and the beginning of time. The dark forked area, called by Proctor "Dawes' Forked Bay," is now commonly called the Sabaeus Sinus. At the times these marine

names were bestowed, it was supposed that the dark markings really represented water. We have now reason to believe that such is not the case. But it is better to keep the old names, although I shall employ them in a Pickwickian sense, much as we still speak of the Seas of the Moon, the Mare Tranquillitatis, or the Mare Serenitatis, of which only the adjectives have in them anything of truth

To the west of the Sabaeus Sinus lies another dark, wedge-shaped area, longer than it but single instead of double. This is the Margaritifer Sinus, or the Pearl-bearing Gulf, so named before it was known that that name possessed any significance. But a prescience must have presided over its christening For we now know that there is indeed a pearl at the bottom of it, — the round spot shown in the picture

Two lines will be noticed prolonging the twin forks of the Sabaeus Sinus. If we let our look follow down them, we shall mark others and then yet others, and so we might proceed from line to line all over the bright areas of the planet. These lines are the famous canals of Mars. With regard to their surprising symmetry, it is only necessary to say that the better they are seen the more symmetrical they look. Of the two first mentioned, the right-hand one is the Gihon, the left-hand one the Hiddekel,

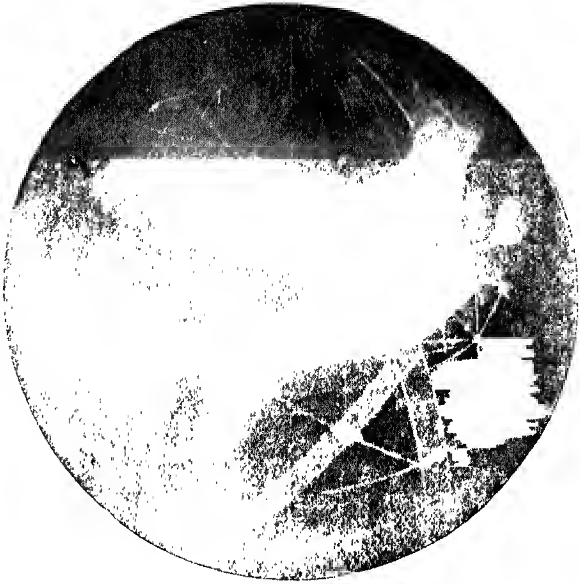
PLATE III



MARS
LONGITUDE 0° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

PLATE IV



P. L.

MARS
LONGITUDE 30° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

and the spot at the limit of the latter is the Lacus Ismenius. From the pearl at the bottom of the Margaritifer Sinus, the Oxia Palus, the Oxus runs nearly north to the Pallas Lacus, while another canal, the Indus, makes off northwest.

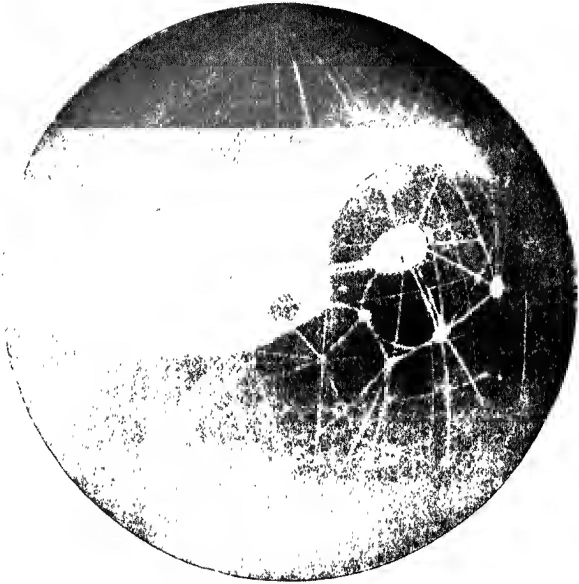
Nearly in the centre of the disk are seen two of those strange comet-tail peninsulas that constitute so peculiar a feature of Martian geography. The lower is Deucalionis Regio; the upper, Pyrrhae Regio. Across them show two streaks, which, followed up, will be found to join other streaks traversing the dark regions. These introduce us to Mr. Douglass' discovery of a whole system of canals in the dark regions, paralleling the system in the bright areas,—being similarly straight and similarly intersecting one another, with spots at the intersections, making what Mr. Douglass aptly terms a checkerboard effect, as we shall see more strikingly when we get round to the other side of the planet.

In Plate IV. the markings have, under the rotation of the planet, all swung 30° to the east, thus bringing others into view from the west. The great swath obliquely belting the disk is the canal called the Jamuna. It was, at the time this picture represents it, apparently in process of doubling. Crossing it obliquely is the Hydraotes. More conspicuous are two dark

swaths that make with the Jamuna a nearly right-angled triangle. The lower one parallel to the edge of the disk is the Dardanus; the other, ending at the south with the Jamuna in the Aurorae Sinus, is the Ganges, one of the largest and most important of the Martian canals. At the date of the drawing, it was distinctly double. The doubling is very curiously prolonged by a narrow rectangle lying in the midst of the dark regions to the south. Some idea of the size of these strangely geometrical markings may be got by remembering that a degree on Mars represents thirty-seven miles. Skirting the edge of the dark regions westward, we come to a short canal, the Hebe, leading to the Fons Juventae, one of the tiniest markings perceptible on the disk, from which, however, some six canals have been found to radiate. Schiaparelli detected it in 1877, searched for it in vain in 1879, but at subsequent oppositions found it again, happier than Ponce de Leon in his futile quest after an earthly Fountain of Youth. Proceeding still farther west, we reach the entrance to the Agathodaemon, at the point where the edge of the dark regions abruptly trends southward. This canal brings us to the Solis Lacus region, one of the most interesting parts of the planet.

In Plate V. it has swung round into better view, where we will therefore consider it.

PLATE V



P L

MARS
LONGITUDE 60° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

The Solis Lacus is a great oval patch, measuring along its longest diameter five hundred and forty miles. With small telescopic power or in poor air it appears of uniform tint throughout, but under better visual conditions dark spots appear in it, and bright causeways, which divide it into five portions. Its longitudinal dividing line is prolonged into the Nectar, the short canal connecting it with the dark regions to the east. The Nectar thus appears double. Nor does the causeway stop here. It continues on between double dark lines until it reaches the long rectangular area spoken of before as a sort of continuation of the Ganges.

But a second feature of this region is no less noteworthy. Surrounding the Solis Lacus is a perfect cordon of canals and spots, the chief of which are the Tithonius Lacus, nearly due north, and the Lacus Phoenicis, or Phoenix Lake, northwest. The spots are strung like beads upon the loop of the Agathodaemon and the Daemon. From the northeast end of this string of spots runs the Chrysorrhoas to the Lacus Lunae on the fifty-eighth meridian. Below it is the Labeatis Lacus, from which the Gigas starts west, to be lost in the limb-light.

In the next plate (Plate VI.), the Solis Lacus is central, the Lacus Phoenicis somewhat to the right of the centre; and southwest of the Lacus Phoenicis is the Beak of the Sirens, the eastern

end of the sea of the same name, which has just come round the corner of the disk. The canal connecting it with the Phoenix Lake is the Araxes; and at various angles to this, like spokes of a wheel about the Phoenix Lake for hub, are many more canals, the one lying most nearly due south being the Phasis. Connecting with this network of canals is a similar network of streaks in the dark regions, making a set of triangles, from which still other canals run up almost straight toward the south pole.

Between the dark regions and the Beak of the Sirens is the peninsula Phaetontis, crossing which some way up is a short canal known as Herculis Columnae. Due north of the Lacus Phoenicis is the spot Ceraunius, joined to the Lacus Phoenicis by the Iris, and to the Tithonius Lacus by the Fortunae. It is also crossed by the Gigas, the very long canal in the right-hand lower part of the disk, of which we saw the beginning in the last plate, and shall not see the end till we reach the next one.

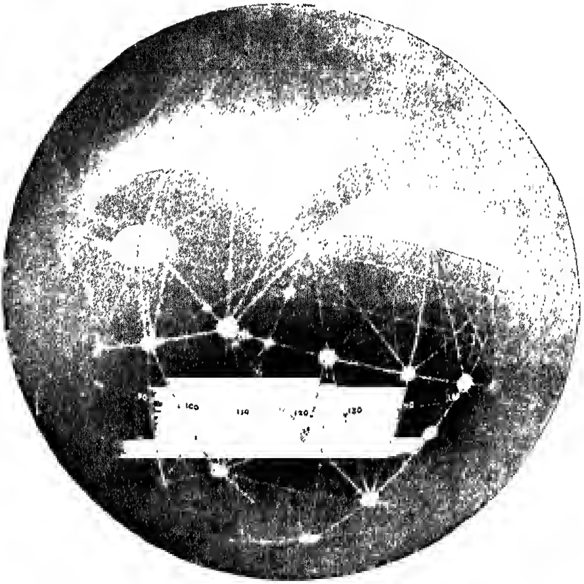
Westward of the Lacus Phoenicis there begins to show a congeries of spots and connecting canals, which come out still more strikingly in Plate VII. The great canal beaded with spots, which in the picture traverses nearly the centre of the disk, is the Eumenides, and its continuation, the Orcus. Its farther end is lost in the limb-light. At an angle to it, running nearly

Plate VI

MARS
Longitude 90° on the Meridian

Lowell Observatory
Flagstaff, A. T. 1895

Plate VII



MARS
Longitude 120° on the Meridian

Lowell Observatory
Flagstaff, A. T. 1895

northwest from the Lacus Phoenicis, is the Pyriphlegethon. In this plate the Sea of the Sirens is well on, its beak being almost on the central meridian. From its north coast strike down a great many canals, all going as far as the Eumenides and some continuing past it. The first one from the Beak of the Sirens is the Sirenius. It crosses the Eumenides at the first of its large spots after leaving the Phoenix Lake, the Lucus Arsine. To the next spot, known as the Nodus Gordii, the Gorgon comes down from the centre of the coast-line, meeting the Gigas, which itself debouches, at the west end of the sea, into what is called the Sinus Titanum, or Gulf of the Titans.

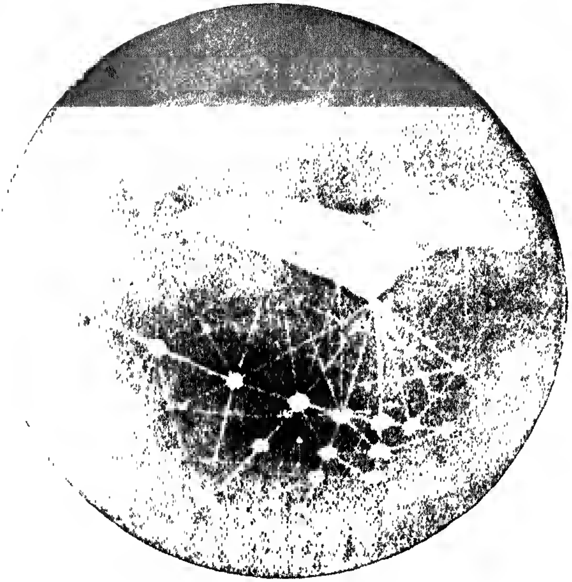
In Plate VIII. the Sinus Titanum has come round into view. Owing to its conspicuousness at certain seasons, it is one of the most important features on the planet to us, and seems to be to the planet itself, as some seven canals radiate from it. These are the Gigas, previously described, and to the right, in the order here enumerated, the Steropes, the Brontes, the Titan, — the one straight down the disk, — the Arges, the Gyes, and the Tartarus; the last traveling to the Trivium Charontis invisible in this plate. Of the separate existence of the Arges and the Gyes I am not quite certain. These great canals show like the sticks of a fan, with the Sinus itself for pivot.

The Sea of the Sirens is now nearly central. To the west, dividing it from the Mare Cimmerium, which is just coming into view, is the peninsula Atlantis, curiously uniting the continents to the islands to the south. Belting the disk from east to west is the Eumenides-Orcus, strung with spots.

Parallel to the Eumenides-Orcus, and skirting the north shore of the Sea of the Sirens, is the Erynnis. Half way between this and the Eumenides is another parallel canal, the Parcae. Curving round the bottom of the disk is a chain of canals, the Pyriphlegethon, Acheron, and Erebus, the last of which runs to the Trivium Charontis. At the junctions of these various canals may be seen any number of spots.

On the next plate (Plate IX.) the Trivium Charontis itself has come into view toward the lower right-hand part of the disk. Two nearly parallel canals, a double Hades, join it to the Propontis, the spot almost at the limb. The Titan shows well near the centre of the disk. Were the centre ten degrees farther east, the canal would appear more striking yet. For so straight is it, and so nearly due north and south does it lie, that when it comes to the meridian it seems that meridian itself. On this plate we have the western end of the Eumenides-Orcus, at whose eastern end we began several plates back when we left the Phoenix Lake. This will give some

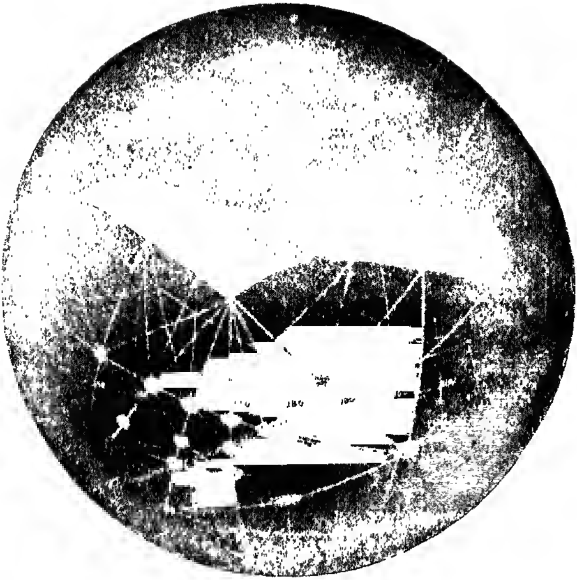
PLATE VIII



MARS
LONGITUDE 150° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

Plate IX



P. L.

MARS
Longitude 180° on the Meridian

Lowell Observatory
Flagstaff, A. T. 1895

idea of the immense length of the canal, which is no less than three thousand four hundred and fifty miles long. Nearly in the centre of the disk is the peninsula Atlantis, the most easterly of the set of comet-tail peninsulas similar to those seen in Plate I., all connecting the so-called continent with the islands to the south. These islands look not unlike great vertebrae of the planet's backbone, in consequence of the canals which cut them up so symmetrically. Atlantis shows well, between Mare Sirenum and Mare Cimmerium, two areas suggestively alike in general shape and directional trend. Both are seen to be crossed by canals which connect, at what resemble nicks in the coast-line, with the canals in the bright regions.

In Plate X. the Mare Cimmerium is central. So, also, well down the disk, is the Trivium Charontis. This is a very important junction, no less than nine canals already being known to connect with it, which, taken in the order, east, north, west, and south, are the Orcus, the Erebus, the twin Hades, the Styx, the Cambyses, the Cerberus, the Laestrygon, the Tartarus, and so back to the Orcus again. In this picture the Laestrygon traverses nearly the centre of the disk. To the right of the Trivium Charontis is the region called Elysium, one of the brightest parts of the planet. It was here that Mr. Douglass made his interest-

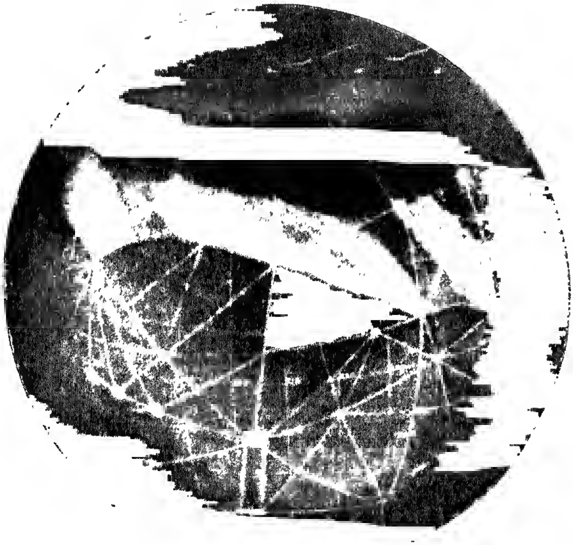
ing observation, last September, of a remarkable change of tint from bright to sombre, and back to bright again, in the course of forty-eight hours; suggesting perhaps the formation and dissipation of cloud, perhaps the deposition and subsequent melting of hoar-frost over an area of some hundreds of square miles.

Returning to the Mare Cimmerium, we observe in the middle of it a long, lighter streak, Cimmeria, scarcely perceptible at this last opposition, and, barring its western end, the second in the procession of similarly inclined peninsulas that follow one another westward upon this side of the planet, the peninsula Hesperia, a place with a history, as will appear later on.

In the next picture (Plate. XI) Hesperia is central, dividing the Mare Cimmerium on the left from the Mare Tyrrhenum on the right. The lower end of the latter is called the Syrtis Minor, in contradistinction to the Syrtis Major, which is just appearing round the western limb. From the bay, so to speak, upon the left of Hesperia, two canals proceed down the disk in divergent directions, — the most easterly one the Aethiops, the other the Achelous. From the Syrtis Minor proceed two others, more or less similarly inclined, — the Lethes and the Amenthes.

To the west of Hesperia and parallel to it is a third comet-tail peninsula, Lemuria, connect-

PLATE X



F. L.

MARS

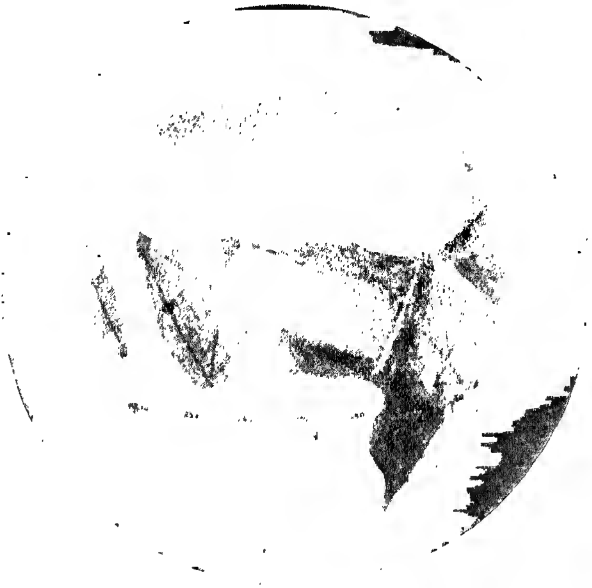
LONGITUDE 210° ON THE MERIDIAN

LOWELL OBSERVATO
Flagstaff, A. T. 189

MARS
LONGITUDE 240° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

PLATE XII



MARS
LONGITUDE 270° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

ing Ausonia at the south with Libya to the north, Libya being upon the equator. This region (Plate XII.) is interesting as having been the scene of great changes at previous oppositions. There used to be a spot, the Lake Moeris, in the midst of it, joined by the Nepenthes — the canal running east and west about eight degrees north of the equator — to the Syrtis Major, the great dark gulf somewhat to the west of the central meridian in the picture. Latterly the Syrtis Major seems to have encroached upon Libya, and, at the last opposition, only the faintest glimpses could be got of Lake Moeris, which showed chiefly as a bay of the Syrtis Major itself. Here, as elsewhere, I use aquatic names with terrestrial understanding.

Parallel in a general way to the Nepenthes, and about as much below it as it is below the coast-line, lies the Astapus, which joins the bottom of the Syrtis Major to the ends of the Amenthes, Lethes, and Achelous.

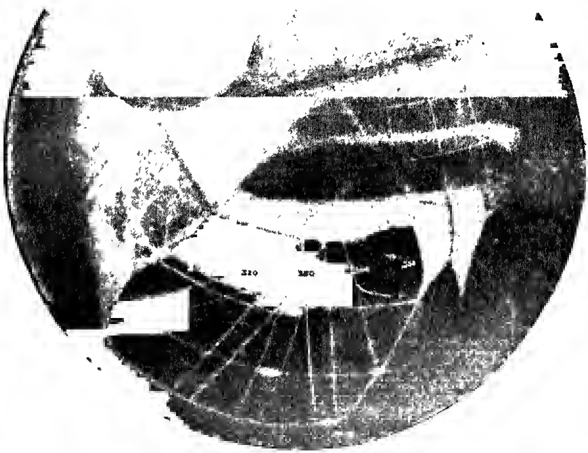
In Plate XIII. two features are striking, both not far from central on the disk, — the lower, the Syrtis Major; the upper, Hellas. The Syrtis Major was the first marking to be certainly recognized on Mars. It appears in a drawing by Huyghens made on October 13, 1659, the first drawing of Mars worthy the name ever made by man, and reproduced on

page 20 from Flammarion's "La Planète Mars." It is thus our oldest Martian acquaintance. Hellas is the surprisingly round, bright area nearly on the meridian, and nearly half way from the equator to the south pole. It is very strangely quartered by two canals, the Alpheus, dividing it almost due north and south; and the Peneus, cutting it almost due east and west. Between it and the Syrtis Major is the Mare Hadriaticum, a blue-green area intersected by bright causeways and seamed by dark canals.

In the lower right-hand portion of the disk is an important region, bounded on the east by the Syrtis Major, on the north by the Nilosyrtis and the Protonilus, on the west by the Hiddekel, and on the south by the long dark area to the north of Deucalionis Regio. Its south-eastern cape is the Hammonis Cornu; its south-western one, which appears in Plate XIV., is the Edom promontory. It is a region prolific in double canals. The two most important of these are the Phison and the Euphrates. Both start from the centre of the coast of the long dark area between the Deucalionis Regio and the continent, and run, the Phison northeast to the western end of the Nilosyrtis, in longitude 300°, latitude 33° north; the Euphrates, nearly due north to the Lacus Ismenius, longitude 337°, latitude 37° north, where it connects with the Hiddekel. Parallel to the coast-line and

MARS
LONGITUDE 300° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895



MARS
LONGITUDE 330° ON THE MERIDIAN

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

about 15° to the north of it is, on the east, the Typhon, shown double; on the west the Orontes, still single. Two other doubles shown in the picture I saw also in this region, though I am not yet certain that they are distinct from the Phison and the Euphrates, as the four were not seen together. I have introduced them in the place where I saw them, because, first, no optical effect explains any such shift; and, second, they run through and to well-seen spots, which renders it more likely that they are distinct canals.

Between the Euphrates and the Sabaeus Sinus are several canals and spots that show the minute manner in which the Martian surface is cut up. But so much only hints at the state of things existent there. From the markings, not well enough seen to admit of mapping, it is apparent that the system of lines and spots is very complete all over the planet.

This brings us back again to the Sabaeus Sinus and the Fastigium Aryn, from which we set out, after a journey which it takes the rotation of the planet twenty-four hours thirty-seven minutes and about twenty-three seconds to accomplish.

III. SEAS.

While it existed in any size, the polar sea was bordered on the north, all the way round

and during all the time it was visible, by blue-green areas. These blue-green areas were strewn with several more or less bright regions, while below them came the great reddish-ochre stretches of the disk. Now, the blue-green areas have generally been considered to be seas, just as the reddish-ochre regions have been held to be land. That the latter are land there is very little doubt; not only land, but nothing but land, — land very pure and simple; that is, deserts. For they behave just as deserts should behave, that is, by not behaving at all; remaining, except for certain phenomena to be specified later, unchangeable.

With the so-called seas, however, the case is different. Several important facts conspire to throw grave doubt, and worse, upon their aquatic character. To begin with, they are of every grade of tint, — a very curious feature for seas to exhibit, unless they were everywhere but a few feet deep; which again is a most singular characteristic for seas that cover hundreds of thousands of square miles in extent, — seas, that is, as big as the Bay of Bengal. The Martian surface would have to be amazingly flat for this to be possible. We know it to be relatively flat, but to be as flat as all this would seem to pass the bounds of credible simplicity. Here also Professor W. H. Pickering's polariscope investigations come in with

effect, for he found the light from the supposed seas to show no trace of polarization. Hence these were probably not water.

In parenthesis we may here take notice of the absence of a certain phenomenon whose presence, apparently, should follow upon water surfaces such as the so-called seas would offer us. Although its absence is not perhaps definitive as to their marine character, it is certainly curious, and worth noting. If a planet were covered by a sheet of water, that water surface would, mirror-like, reflect the sun in one more or less definite spot. Looked at from a distance, this spot would, were it bright enough, be seen as a high light on the dark background of the ocean about it. It would seem to be a fixed star at a certain point on the disk, the surface features rotating under it. The necessary position is easily calculated, and this shows that parts of the so-called seas, especially at oppositions like the last one, pass under the point. There remains merely the question of sufficient brilliancy in the spot for visibility; but as in the case of Mars its brilliancy should be equal to that of a star of the first magnitude, it would seem brilliant enough to be seen. No such starlike effect in such position has ever been noticed coming from the blue-green regions. From this bit of negative evidence, to be taken for what it is worth, we return again to what there is of a positive sort.

Not only do different parts of the so-called seas contrast in tint with one another, but the same part of the same sea varies in tint at different times. Schiaparelli noticed that, at successive oppositions, the same sea showed different degrees of darkness, and he suggested that the change in tone was dependent in some way upon the Martian seasons.

Observations at Flagstaff have demonstrated this to be the case, for it has been possible to see the tints occur consecutively. In consequence, we know not only that changes take place on the surface of Mars other than in the polar cap, and very conspicuous ones too, but that these are due to the changing seasons of the planet's year. We will now see what they look like.

To the transubstantiation of changes of the sort it is a prime essential that the drawings from whose comparison the contrast appears should all have been made by the same person, at the same telescope, under as nearly as possible the same atmospheric conditions, since otherwise the personal equation of the observer, the impersonal inequalities of instruments, and the special atmosphere of the station play so large a part in the result as to mask that other factor in the case, any change in the planet itself. How easily this masking is accomplished appears from drawings made by different ob-

Fig. I. Syrtis Major at June presentation
Long. 290°. Lat. centre of disk 24° South

Fig. II. Syrtis Major at October presentation
Long. 305°. Lat. centre of disk 20° South

SYRTIS MAJOR

Showing seasonal change during 1894

Lowell Observatory
Flagstaff, A. T. 1894

servers of the same Martian features at substantially the same moment. Several interesting specimens of such personal peculiarities may be seen by the curious in Flammarion's admirable thesaurus, "La Planète Mars." In some of these likenesses of the planet it is pretty certain that Mars would never recognize himself.

To have drawings simply swear at one another across a page is, in the interests of deduction, objectionable. For their testimony to be worth having, they must agree to differ. If, therefore, Mars is to be many, his draughtsman must be one. So much, at least, is fulfilled by the drawings in which the changes now to be described are recorded; for they were all made by me, at the same instrument, under the same general atmospheric conditions. As the same personality enters all of them, it stands, as between them, eliminated from all, to increased certainty of deduction. Since, furthermore, the drawings were all made in the months preceding and following one opposition, change due to secular variation is reduced to a minimum. As a matter of fact, the changes are such as to betray their own seasonal character. They constitute a kinematical as opposed to a statical study of the planet's surface.

The changes are much more evident than might be supposed. Indeed, they are quite unmistakable. As for their importance, it need

only be said that deduction from them furnishes, in the first place, inference that Mars is a living world, subject to an annual cycle of surface growth, activity, and decay; and shows, in the second place, that this Martian yearly round of life must differ in certain interesting particulars from that which forms our terrestrial experience. The phenomena evidently make part of a definite chain of changes of annual development. So consecutive, and, in their broad characteristics, apparently so regular, are these changes, that I have been able to find corroboration of what appears to be their general scheme in drawings made at a previous opposition. In consequence, I believe it will be possible in future to foretell, with something approaching the certainty of our esteemed weather bureau's prognostications, not indeed what the weather will be on Mars, — for, as we have seen, it is more than doubtful whether Mars has what we call weather to prognosticate, — but the aspect of any part of the planet at any given time.

The changes in appearance now to be chronicled refer, not to the melting of the polar snows, except as such melting forms the necessary preliminary to what follows, but to the subsequent changes in look of the surface itself. To their exposition, however, the polar phenomena become inseparable adjuncts, since they are inevitable ancillaries to the result.

With the familiar melting of the snow-cap begins the yearly round of the planet's life. With the melting of our own arctic or antarctic cap might similarly be said to begin the earth's annual activity. But here at the very outset there appears to be one important difference between the two planets. On the earth the relation of the melting of the polar snows to the awakening of surface activity is a case of *post hoc* simply; on Mars it seems to be a case of *propter hoc* as well. For, unlike the earth, which has water to spare, and to which, therefore, the unlocking of its polar snows is a matter of no direct economic value, Mars is apparently in straits for the article, and has to draw on its polar reservoir for its annual supply. Upon the melting of its polar cap, and the transference of the water thus annually set free to go its rounds, seem to depend all the seasonal phenomena on the surface of the planet.

The observations upon which this deduction is based extend over a period of nearly six months, from the last day of May to the 22d of November. They cover the regions from the south pole to about latitude forty north. That changes analogous to those recorded, differing, however, in details, occur six Martian months later in the planet's northern hemisphere, is proved by what Schiaparelli has seen; for though the general system is, curiously, one for

the whole planet, the particular character of different parts of the surface alters the action there to some extent.

For an appreciation of the meaning of the changes, it is to be borne in mind throughout that the vernal equinox of Mars' southern hemisphere occurred on April 7, 1894; the summer solstice of the same hemisphere on August 31; and its autumnal equinox on February 7, 1895.

On the 31st of May, therefore, it was toward the end of April on Mars. The south polar cap was, as we have seen, very large, and the polar sea in proportion. That the polar sea was the darkest and the bluest marking on the disk implies that it was, at least, the deepest body of water on the planet, whether the so-called seas were seas or not. But from the fact that it was quite wide, — 350 miles, — and that it all eventually vanished, it can hardly have been very deep. Its relative appearance, therefore, casts a first doubt upon the fact that the others were seas at all. This polar sea plays *deus ex machina* to all that follows.

So soon as the melting of the snow was well under way, long straits, of deeper tint than their surroundings, made their appearance in the midst of the dark areas. I did not see them come, but as I afterward saw them go it is evident that they must have come. They were

already there on the last day of May. The most conspicuous of them lay between Noachis and Hellas, in the Mare Australe. It began in the great polar bay, and thence traversed the Mare Erythræum to the Hourglass Sea (Syrtis Major). The next most conspicuous one started in the other bay, and came down between Hellas and Ausonia. Although these straits were distinguishably darker than the seas through which they passed, the seas themselves were then at their darkest. The fact that these straits traversed the seas suffices to raise a second doubt as to the genuineness of seas; the first suspicion as to their character — coming from their being a little off color; not so blue, that is, as what we practically know to be water, the polar sea — finding thus corroboration. It will appear later that in all probability the straits themselves were impostors, and that neither seas nor straits were water.

The appearance of things at this initial stage of the Martian Nile-like inundation last June was most destructive to modern maps of Mars, for all the markings between the south polar cap and the continental coast-line seemed with one consent to have, as nearly as might be, obliterated themselves.

It was impossible to fix any definite boundaries to the south temperate chain of islands, so indistinguishably did the light areas and the

dark ones merge into each other. What was still more striking, the curious peninsulas which connect the continent with the chain of islands to the south of it, and form so singular a feature of the planet's geography, were invisible. One continuous belt of blue-green stretched from the Syrtis Major to the Columns of Hercules.

For some time the dark areas continued largely unchanged in appearance; that is, during the earlier and most extensive melting of the snow-cap. After this their history became one long chronicle of fading out. Their lighter parts grew lighter, and their darker ones less dark. For, to start with, they were made up of many tints; various shades of blue-green interspersed with glints of orange-yellow. The gulfs and bays bordering the continental coast were the darkest of these markings; the long straits between the polar sea and the Syrtis Major were the next deepest in tone.

The first marked sign of change was the reappearance of Hesperia. Whereas in June it had been practically non-existent, by August it had become perfectly visible and in the place where it is usually depicted. In connection with its reappearance two points are to be noted: first, the amount of the change, for Hesperia is a stretch of land over two hundred miles broad by six hundred miles long; and,

PLATE XVI

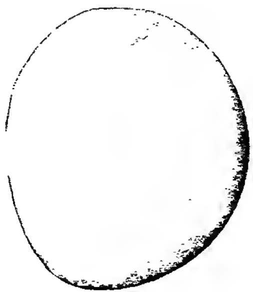


FIG. I. Hesperia at June presentation
Long. 242°. Lat. centre of disk 24° South

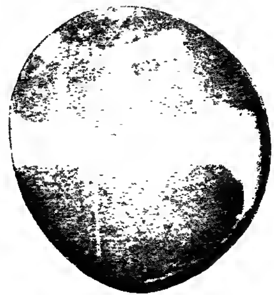


FIG. II. Hesperia at August presentation
Long. 247°. Lat. centre of disk 17° South

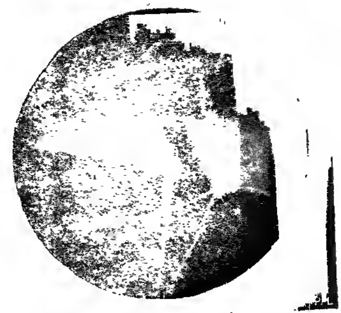


FIG. III. Hesperia at October presentation
Long. 237°. Lat. centre of disk 21° South

HESPERIA

SHOWING SEASONAL CHANGE DURING 1894

secondly, the fact that its previous invisibility was not due to any sort of obscuration. The persistent clear-cut character of the neighboring coast-line during the whole transformation showed that nothing of the nature of mist or cloud had at any time hidden the peninsula from view. A something was actually there in August which had not been there in June.

As yet nothing could be seen of Atlantis. It was not until the 30th of October that I caught sight of it. About the same time, the straits between the islands, Xanthus, Scamander, Psychrus, and Simois, came out saliently dark, a darkness due to contrast. The line of south temperate islands, with their separate identity, was then for the first time apparent.

Meanwhile the history of Hesperia continued to be instructive. From having been absent in June and conspicuous in August, it returned in October to a mid-position of visibility. Vacillating as these fluctuations in appearance may seem at first sight, they were really quite consistent; for they were probably due to progressive change in the one direction, a change that was manifested first in Hesperia itself, and then in the regions round about it. From June to August, Hesperia changed from a previous blue-green, indistinguishable from its surroundings, to yellow, the parts adjacent remaining much as before. As a consequence, the pe-

ninsula stood out in marked contrast to the still deep blue-green regions by its side. Later the surroundings themselves faded, and their bleaching had the effect of once more partially obliterating Hesperia.

While Hesperia was thus getting itself noticed, the rest of the south temperate zone, as we may call it for identification's sake, was unobtrusively pursuing the same course. Whereas in June all that part of the disk comprising the two Thyle, Argyre II., and like latitudes was chiefly blue-green, by October it had become chiefly yellow. Still further south, what had been first white, then blue, then brown, turned ochre.

Certain smaller details of the change that came over the face of the dark regions at the time were as curious as they were marked. For example, the Fastigium Aryn, the tip of the triangular cape which, by jutting out from the continent, forms the forked bay called the Sabaeus Sinus, and which, because of its easy identification, has been selected for the zero meridian of Martian longitudes, began in October to undergo strange metamorphosis. On October 15 it shot out a sort of tail southward. On the 16th this tail could be followed all the way to Deucalionis Regio, to which it made a bridge across from the continent, thus cutting the Sabaeus Sinus completely in two. After it

had thus appeared, it continued visible up to the close of the observations sufficiently detailed to show it.

Another curious causeway of the same sort made its appearance in November, connecting the promontory known as Hammonis Cornu with Hellas. Both of these necks of orange-ochre were of more or less uniform breadth throughout.

The long, dark streaks that in June had joined the Syrtis Major to the polar sea had by October nearly disappeared; in their southern parts they had vanished completely, and they had very much faded in their northern ones. The same process of fading uncovered certain curious rhomboidal bright areas in the midst of the Syrtis Major.

It will be seen that the extent of these changes was enormous. Their size, indeed, was only second in importance to their character; for it will also have been noticed that the changes were all in one direction. A wholesale transformation of the blue-green regions into orange-ochre ones was in progress upon that other world.

What can explain so general and so consecutive a change in hue? Water suggests itself; for a vast transference of water from the pole to the equator might account for it. But there are facts connected with the change which seem

irreconcilable with the idea of water. In the first place, Professor W. H. Pickering found that the light from the great blue-green areas showed no trace of polarization. This tended to strengthen a theory put forth by him some years ago, that the greater part of the blue-green areas are not water, but something which at such a distance would also look blue-green, namely, vegetation. Observations at Flagstaff not only confirm this, but limit the water areas still further; in fact, practically do away with them entirely. Not only do the above polariscopic tests tend to this conclusion, but so does the following observation of mine in October.

Toward the end of October, a strange, and, for observational purposes, a distressing phenomenon took place. What remained of the more southern dark regions showed a desire to vanish, so completely did those regions proceed to fade in tint throughout. This was first noticeable in the Cimmerian Sea, then in the Sea of the Sirens, and in November in the Mare Erythraeum about the Lake of the Sun. The fading steadily progressed until it had advanced so far that in poor seeing the markings were almost imperceptible, and the planet presented a nearly uniform ochre disk.

This was not a case of obscuration; for in the first place it was general, and in the second place the coast-lines were not obliterated. The

change, therefore, was not due to clouds or mist.

What was suggestive about the occurrence was that it was unaccompanied by a corresponding increase of blue-green elsewhere. It was not simply that portions of the planet's surface changed tint, but that, taking the disk in its entirety, the whole amount of the blue-green upon it had diminished, and that of the orange-yellow had proportionally increased. Mars looked more Martian than he had in June. The canals, indeed, began at the same time to darken; but, highly important as this was for other reasons, the whole area of their fine lines and associated patches did not begin to make up for what the dark regions lost.

If the blue-green color was due to water, where had all the water gone? Nowhere on the visible parts of the planet; that is certain. Nor could it very well have gone to those north circumpolar regions hid from view by the tilt of the disk; for there was no sign of a growing north polar cap, and, furthermore, Schiaparelli's observations upon that cap show that there should not have been. At the opposition of 1881, he found that it developed late, apparently one month or so after the vernal equinox of its hemisphere, whereas at the time the above change occurred it was not long after that hemisphere's winter solstice.

But if, instead of being due to water, the blue-green tint had been due to leaves and grasses, just such a fading out as was observed should have taken place as autumn came on, and that without proportionate increase of green elsewhere; for the great continental areas, being desert, are incapable of supporting vegetation, and therefore of turning green.

Thus we see that several independent phenomena all agree to show that the blue-green regions of Mars are not water, but, generally at least, areas of vegetation; from which it follows that Mars is very badly off for water, and that the planet is dependent on the melting of its polar snows for practically its whole supply.

Such scarcity of water on Mars is just what theory would lead us to expect. Mars is a smaller planet than the Earth, and therefore is relatively more advanced in his evolutionary career. He is older in age, if not in years; for whether his birth as a separate world antedated ours or not, his smaller size, by causing him to cool more quickly, would necessarily age him faster. But as a planet grows old, its oceans, in all probability, dry up, the water retreating through cracks and caverns into its interior. Water thus disappears from its surface, to say nothing of what is being continually imprisoned by chemical combination. Signs of having thus parted with its oceans we see in the case of the

PLATE XVII

I

II

P. L.

FIG. I. Sea of the Sirens at June presentation
Long. 141°. Lat. centre of disk 24° South

FIG. II. Sea of the Sirens at November presentation
Long. 156°. Lat. centre of disk 22° South

SEA OF THE SIRENS AND ATLANTIS
AT THE OPPOSITION OF 1894
SHOWING SEASONAL CHANGE

LOWELL OBSERVATO

Moon, whose so-called seas were probably seas in their day, but have now become old sea-bottoms. On Mars the same process is going on, but would seem not yet to have progressed so far, the seas there being midway in their career from real seas to arid depressed deserts; no longer water surfaces, they are still the lowest portions of the planet, and therefore stand to receive what scant water may yet travel over the surface. They thus become fertilized, while higher regions escape the freshet, and remain permanently barren. That they were once seas we have something more than general inference to warrant us in believing.

There is a certain peculiarity about the surface markings of Mars, which is pretty sure to strike any thoughtful observer who examines the planet's disk, with a two- or a three-inch object-glass, — their singular sameness night after night. With quite disheartening regularity, each evening presents him with the same appearance he noted the evening before, — a dark band obliquely belting the disk, strangely keeping its place in spite of the nightly procession of the meridians ten degrees to the east, in consequence of our faster rotation gaining on the slower rotation of Mars. By attention, he will notice, however, that the belt creeps slowly upwards towards the pole. Then suddenly some night he finds that it has slipped

bodily down, to begin again its Sisyphus-like, inconclusive spiral climb.

Often as this rhumb line must have been noticed, no explanation of it has ever, to my knowledge, been given. Yet so singular an arrangement points to something other than chance. Suspicion of its non-fortuitous character is strengthened when it is scanned through a bigger glass. Increase of aperture discloses details that help explain its significance. With sufficient telescopic power, the continuity of the dark belt is seen to be broken by a series of parallel peninsulas or semi-peninsulas that jut out from the lower edge of the belt, all running with one accord in a southeasterly direction, and dividing the belt into a similar series of parallel dark areas. Such oblong areas are the Mare Tyrrhenum, the Mare Cimmerium, the Mare Sirenum, and those unnamed straits that stretch southeasterly from the Aurorae Sinus, the Margaritifer Sinus, and the Sabaeus Sinus. The islands and peninsulas trending in the same direction are Ausonia, Hesperia, Cimmeria, Atlantis, Pyrrhae Regio, Deucalionis Regio, and the two causeways from the Fastigium Aryn and Hammonis Cornu. It will further be noticed that these areas lie more nearly north and south as they lie nearer the pole, and curve in general to the west as they approach the equator.

With this fact noted, let us return to the water formed by the melting of the ice-cap, at the time it is produced around the south pole. We may be sure it would not stay there long. No sooner liberated from its winter fetters than it would begin, under the pull of gravity, to run toward the equator. The reason why it would flow away from the pole is that it would find itself in unstable equilibrium where it was. Successive depositions of frost would have piled up a mound of ice which, so long as it remained solid, cohesion would keep in that unnatural position; but the moment it changed to a liquid this would flow out on all sides, seeking its level. Once started, its own withdrawal would cause the centre of gravity to shift away from the pole, and this would pull the particles of the water yet more toward the equator. Each particle would start due north; but its course would not continue in that direction, for at each mile it traveled it would find itself in a lower latitude, where, owing to the rotation of the planet, the surface would be whirling faster toward the east, inasmuch as a point on the equator has to get over much more space in twenty-four hours than one nearer the pole. In short, supposing there were no friction, the surface would be constantly slipping away from under the particle toward the east. As a result, the northerly motion of the particle would be con-

tinually changing with regard to the surface into a more and more westerly one. If the surface were not frictionless, friction would somewhat reduce the westerly component, but could never wholly destroy it without stopping the particle.

We see, therefore, that any body, whether solid, liquid, or gaseous, must, in traveling away from the pole of a sphere or spheroid, necessarily deviate to the west as it goes on, if the spheroid itself revolve, as Mars does, in the opposite direction.

Now this inevitable trend induced in anything flowing from the pole to the equator is precisely the one that we notice stereotyped so conspicuously in the Martian south temperate markings. Here, then, we have at once a suspiciously suggestive hint that they once held water, and that that water flowed.

Corroborating this deduction is the fact that the northern sides of all the dark areas are very perceptibly darker than the southern ones; for the northern side is the one which a descending current would plough out, since it is the northern coasts that would be constantly opposing the current's northerly inertia. Consequently, although at present the descending stream be quite inadequate to such task, it still finds its way, from preference, to these lowest levels, and makes them greener than the rest.

Though seas no longer, we perceive, then,

that there is some reason to believe the so-called seas of Mars to have been seas in their day, and to be at the present moment midway in evolution from the seas of Earth to the seas of the Moon.

Now, if a planet were at any stage of its career able to support life, it is probable that a diminishing water supply would be the beginning of the end of that life, for the air would outlast the available water. Those of its inhabitants who had succeeded in surviving would find themselves at last face to face with the relentlessness of a scarcity of water constantly growing greater, till at last they would all die of thirst, either directly or indirectly; for either they themselves would not have water enough to drink, or the plants or animals which constituted their diet would perish for lack of it, — an alternative of small choice to them, unless they were conventionally particular as to their mode of death. Before this lamentable conclusion was reached, however, there would come a time in the course of the planet's history when water was not yet wanting, but simply scarce and requiring to be husbanded; when, for the inhabitants, the one supreme problem of existence would be the water problem, — how to get water enough to sustain life, and how best to utilize every drop of water they could get.

Mars is, apparently, in this distressing plight at the present moment, the signs being that its water supply is now exceedingly low. If, therefore, the planet possess inhabitants, there is but one course open to them in order to support life. Irrigation, and upon as vast a scale as possible, must be the all-engrossing Martian pursuit. So much is directly deducible from what we have learned at Flagstaff of the physical condition of the planet, quite apart from any question as to possible inhabitants. What the physical phenomena assert is this: if there be inhabitants, then irrigation must be the chief material concern of their lives.

At this point in our inquiry, when direct deduction from the general physical phenomena observable on the planet's surface shows that, were there inhabitants there, a system of irrigation would be an all-essential of their existence, the telescope presents us with perhaps the most startling discovery of modern times, — the so-called canals of Mars. These strange phenomena, together with the inferences to be drawn from them, we will now proceed to envisage.

IV

CANALS

I. FIRST APPEARANCES

In the last chapter we saw how badly off for water Mars, to all appearance, is; so badly off that inhabitants of that other world would have to irrigate to live. As to the actual presence there of such folk, the broad physical characteristics of the planet express no opinion beyond the silence of consent, but they have something very vital to say about the conditions under which alone their life could be led. They show that these conditions must be such that in the Martian mind there would be one question perpetually paramount to all the local labor, women's suffrage, and Eastern questions put together — the water question. How to procure water enough to support life would be the great communal problem of the day.

Were Mars like the Earth, we might well despair of detecting signs of any Martians for some time yet. Across the gulf of space that separates us from Mars, an area thirty miles wide would just be perceptible as a dot. It

would, in such case, be hopeless to look for evidence of folk. Anything like London or New York, or even Chicago in its own estimation, would be too small to be seen, so sorry a figure does man cut upon the Earth he thinks to own. From the standpoint of forty millions of miles distance, probably the only sign of his presence here would be such semi-artificialities as the great grain-fields of the West when their geometric patches turned with the changing seasons from ochre to green, and then from green to gold. By his crops we should know him. A tell-tale fact this, for it would be still more likely to be the case with Mars. If the surface of the planet were cultivated at all, it would probably be upon a much more thorough plan than is the case with the Earth. Conditions hold there which would necessitate a much more artificial state of things. If cultivation there be, it must be cultivation largely dependent upon a system of irrigation, and therefore much more systematic than any we have as yet been forced to adopt.

Now, at this point in our investigation, when the broad features of Mars disclose conditions which imply irrigation as their organic corollary, we are suddenly confronted on the planet's face with phenomena so startlingly suggestive of this very thing as to seem its uncanny presentment. Indeed, so amazingly lifelike is their

appearance that, had we possessed our present knowledge of the planet's physical condition before, we might almost have predicted what we see as criterion of the presence of living beings. What confronts us is this: —

When the great continental areas, the reddish-ochre portions of the disk, are attentively examined in sufficiently steady air, their desert-like ground is seen to be traversed by a network of fine, straight, dark lines. The lines start from points on the coast of the blue-green regions, commonly well-marked bays, and proceed directly to what seem centres in the middle of the continent, since most surprisingly they meet there other lines that have come to the same spot with apparently a like determinate intent. And this state of things is not confined to any one part of the planet, but takes place all over the reddish-ochre regions.

The lines appear either absolutely straight from one end to the other, or curved in an equally uniform manner. There is nothing haphazard in the look of any of them. Plotting upon a globe betrays them to be arcs of great circles almost invariably, even the few outstanding exceptions seeming to be but polygonal combinations of the same. Their most instantly conspicuous characteristic is this hopeless lack of happy irregularity. They are, each and all, direct to a degree.

The lines are as fine as they are straight. As a rule, they are of scarcely any perceptible breadth, seeming on the average to be less than a Martian degree, or about thirty miles wide. They differ slightly among themselves, some being a little broader than this; some a trifle finer, possibly not above fifteen miles across. Their length, not their breadth, renders them visible; for though at such a distance we could not distinguish a dot less than thirty miles in diameter, we could see a line of much less breadth, because of its length. Speaking generally, however, the lines are all of comparable width.

Still greater uniformity is observable in different parts of the same line; for each line maintains its individual width, from one end of its course to the other. Although, at and near the point where it leaves the dark regions, some slight enlargement seems to occur, after it has fairly started on its course, it remains of substantially the same size throughout. As to whether the lines are even on their edges or not, I should not like to say; but the better they are seen, the more even they look. It is not possible to affirm positively on the point, as they are practically nearer one dimension than two.

On the other hand, their length is usually great, and in cases enormous. A thousand or fifteen hundred miles may be considered about

the average. The Ganges, for example, which is not a long one as Martian canals go, is about 1,450 miles in length. The Brontes, one of the newly discovered, radiating from the Gulf of the Titans, extends over 2,400 miles; while, among really long ones, the Eumenides, with its continuation the Orcus, the two being in truth one line, measures 3,540 miles from the point where it leaves the Phoenix Lake to the point where it enters the Trivium Charontis,— throughout this whole distance, nearly equal to the diameter of the planet, deviating neither to the right nor to the left from the great circle upon which it set out. On the other hand, the shortest line is the Nectar, which is only about 250 miles in length; sweetness being, according to Schiaparelli its christener, as short-lived on Mars as elsewhere.

That, with very few exceptions, the lines all follow arcs of great circles is proved,—first, by the fact that, when not too long, they show as straight lines; second, that, when seen near the limb, they appear curved, in keeping with the curvature of a spherical surface viewed obliquely; third, that, when the several parts of some of the longer lines are plotted upon a globe, they turn out to lie in one great circle. Apparent straightness throughout is only possible in comparatively short lines. For a very long arc upon the surface of a revolving globe

tilted toward the observer to appear straight it, or its prolongation, must pass through the centre of the disk at the moment. Such, of course, is rarely the case. At times, however, the conditions are strikingly fulfilled by the great canal called the Titan. The Titan starts from the Gulf of the Titans, in south latitude 20°, and runs north almost exactly upon the 169th meridian for an immense distance. I have followed it over 2,300 miles down the disk to about 43° north, as far as the tilt of the planet's axis would permit. As the rotation of the planet swings it round, it passes the central meridian of the disk simultaneously throughout its length, and at that moment comes out so strikingly straight it seems a substantialized meridian itself.

Although each line is the arc of a great circle, the direction taken by this great circle may be any whatsoever. The Titan, as we have seen, runs nearly due north and south. Certain canals crossing this run, on the contrary, almost due east and west. There are others, again, belting the disk at well-nigh every angle between these two extremes. Nor is there any preponderance, apparently, for one direction as against any other. This indifference to direction is important as showing that the rotation of the planet has no bearing upon the inclination of the canals.

But, singular as each line looks to be by it-

self, it is the systematic network of the whole that is most amazing. Each line not only goes with wonderful directness from one point to another, but at this latter spot it contrives to meet, exactly, another line which has come with like directness from quite a different direction. Nor do two only manage thus to rendezvous. Three, four, five, and even seven will similarly fall in on the same spot, — a gregariousness which, to a greater or less extent, finds effective possibility all over the surface of the planet. The disk is simply a network of such intersections. Sometimes a canal goes only from one intersection to another; more commonly it starts with right of continuation, and, after reaching the first rendezvous, goes on in unchanged course to several more.

The result is that the whole of the great reddish-ochre portions of the planet is cut up into a series of spherical triangles of all possible sizes and shapes. What their number may be lies quite beyond the possibility of count at present; for the better our own air, the more of them are visible. About four times as many as are down on Schiaparelli's chart of the same regions have been seen at Flagstaff. But, before proceeding further with a description of these Martian phenomena, the history of their discovery deserves to be sketched here, since it is as strange as the canals themselves.

The first hint the world had of their existence was when Schiaparelli saw some of the lines in 1877, now eighteen years ago. The world, however, was anything but prepared for the revelation, and, when he announced what he had seen, promptly proceeded to disbelieve him. Schiaparelli had the misfortune to be ahead of his times, and the yet greater misfortune to remain so; for not only did no one else see the lines at that opposition, but no one else succeeded in doing so at subsequent ones. For many years fate allowed Schiaparelli to have them all to himself, a confidence he amply repaid. While others doubted, he went from discovery to discovery. What he had seen in 1877 was not so very startling in view of what he afterward saw. His first observations might well have been of simple estuaries, long natural creeks running up into the continents, and even cutting them in two. His later observations were too peculiar to be explained, even by so improbable a configuration of the Martian surface. In 1879 the *canali*, as he called them (channels, or canals, the word may be translated, and it is in the latter sense that he now regards them), showed straighter and narrower than they had in 1877: this not in consequence of any change in them, but from his own improved faculty of detection; for what the eye has once seen it can always see better a second time. As he

gazed they appeared straighter, and he made out more. Lastly, toward the end of the year, he observed one evening what struck even him as a most startling phenomenon, — the twinning of one of the canals: two parallel canals suddenly showed where but a single one had showed before. The paralleling was so perfect that he suspected optical illusion. He could, however, discover none by changing his telescopes or eye-pieces. The phenomenon, apparently, was real.

At the next opposition he looked to see if by chance he should mark a repetition of the strange event, and went, as he tells us, from surprise to surprise; for one after another of his canals proceeded startlingly to become two, until some twenty of them had thus doubled. This capped the climax to his own wonderment, and, it is needless to add, to other people's incredulity; for nobody else had yet succeeded in seeing the canals at all, let alone seeing them double. Undeterred by the general skepticism, he confirmed at each fresh opposition his previous discoveries, which, in view of the fact that no one else did, tended in astronomical circles to an opposite result.

For nine years he labored thus alone, having his visions all to himself. It was not till 1886 that any one but he saw the canals. In April of that year Perrotin, at Nice, first did so. The

occasion was the setting up of the great Nice glass of twenty-nine inches aperture. In spite of the great size of the glass, however, a first attempt resulted in nothing but failure. So, later, did a second, and Perrotin was on the point of abandoning the search for good, when, on the 15th of the month, he suddenly detected one of the canals, the Phison. His assistant, M. Thollon, saw it immediately afterward. After this they managed to make out several others, some single, some double, substantially as Schiaparelli had drawn them; the slight discrepancies between their observations and his being in point of fact the best of confirmations.

Since then, other observers have contrived to detect the canals, the list of the successful increasing at each opposition, although even now their number might almost be told on one's hands and feet.

The reason that so few astronomers have as yet succeeded in seeing these lines is to be found in our own atmosphere. That in ordinary atmosphere the lines are not easy objects is certain. A moderately good air is essential to their detection; and unfortunately the locations of most of our observatories preclude this prerequisite. Size of aperture of the telescope used is a very secondary matter. That Schiaparelli discovered the canals with an $8\frac{1}{3}$-inch glass, and that the 26-inch glass at Washington

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October, 1894

Lowell Observat
Flagstaff, A. T. 18

has refused to show them to this day, are facts that speak emphatically on the point.

The importance of atmosphere in the study of planetary detail is far from being appreciated. It is not simply question of a clear air, but of a steady one. To detect fine detail, the atmospheric strata must be as evenly disposed as possible.

Next in importance to a steady air comes attentive perception on the part of the observer. The steadiest air we can find is in a state of almost constant fluctuation. In consequence, revelations of detail come only to those who patiently watch for the few good moments among the many poor. Nor do I believe even average air to be entirely without such happy exceptions to a general blur. In these brief moments perseverance will show the canals as faint streaks. To see them as they are, however, an atmosphere possessing moments of really distinct vision is imperative. For the canals to come out in all their fineness and geometrical precision, the air must be steady enough to show the markings on the planet's disk with the clear-cut character of a steel engraving. No one who has not seen the planet thus can pass upon the character of these lines.

Although skepticism as to the existence of the so-called canals has been now pretty well dispelled by these and other observations, dis-

belief still makes a desperate stand against their peculiar appearance, dubbing accounts of their straightness and duplication as sensational, whatever they may mean in such connection; for that they are both straight and double, as described, is certain, — a statement I make after having seen them, instead of before doing so, as is the case with the gifted objectors. Doubt, however, will not wholly cease till more people have seen them, which will not happen till the importance of atmosphere in the study of planetary detail is more generally appreciated than it is to-day. To look for the canals with a large instrument in poor air is like trying to read a page of fine print kept dancing before one's eyes, with the additional disadvantage that increase of magnification increases the motion. Advance in our study of other worlds depends upon choosing the very best atmospheric sites for our observatories.

It is interesting to recall, in connection with this incredulity about the canals, that precisely the same thing happened in the case of the discovery of Jupiter's satellites and with Huyghens' explanation of Saturn's ring. We are apt to imagine that our age of the world has a monopoly of skepticism. But this is a mistake. The spirit that denies has always been abroad; only in early days he was reputed to be the devil.

II. MAP AND CATALOGUE

As we shall now have to call these Martian things by their names, — our names, that is, — it may be well to consider cursorily the nomenclature which has been evolved on the subject. Unfortunately, the planet has been quite too much benamed, — benamed, indeed, out of all recognition. There are no less than five or six systems current for its general topographical features. The result is that it has become something of a specialty just to know the names. The Syrtis Major, for example, appears under the following aliases: the Syrtis Major, the Mer du Sablier, the Kaiser Sea, the Northern Sea, to say nothing of translations of these, such as the Hourglass Sea; after which ample baptism it is a trifle disconcerting to have the sea turn out, apparently, not to be a sea at all. Everybody has tried his hand at naming the planet, first and last; naming a thing being man's nearest approach to creating it. Proctor made a chart of the planet, and named it thoroughly; Flammarion made another chart, and also named it thoroughly, but differently; Green drew a third map, and gave it a third set of names; Schiaparelli followed with a fourth, and furnished it with a brand-new set of his own; and finally W. H. Pickering found it necessary to give a few new names, just for

particularization. To know, therefore, what part of the planet anybody means when he mentions it, one has to keep in his head enough names for five worlds. To cap which, it is to be remarked that not one of them is the thing's real — that is, its Martian — name, after all!

Fortunately, with the canals, matters are not so desperate, because so few people have seen them. Schiaparelli's monopoly of the sight pleasingly prevented, in their case, christening competition. What is more, he named them, very judiciously and most picturesquely, after mythologic river names. Where he got his names is another matter. Whether he started by being as learned in such lore as he afterward became may well be doubted. Certainly, one of the greatest discoveries made at Flagstaff has been the discovery of the meaning of Schiaparelli's names; some of them still defying the penetrating power of the ordinary encyclopædia. Among them are classical mythologic ones of the class known only to that himself mythical character, Macaulay's every schoolboy; which speaks conclusively for their reconditeness. Others, I firmly believe, even that omniscient schoolboy can never have heard of. Want of space here precludes instances; but as a simple example I may say that the translation to Mars of the Phison and the Gihon, the two lost rivers of Mesopotamia, satisfactorily ac-

counts for their not being found on earth by modern explorers.

With due mental reservation as to their meaning, I have adopted Schiaparelli's names, and, where it has been necessary to name newly discovered canals, have conformed as closely as possible to his general scheme. If, even in an instance or two, I have hit upon names that are incomprehensible, I shall feel that I have not disgraced my illustrious predecessor. For a brand-new thing no name is so good as one whose meaning nobody knows, except one that has no meaning at all. In that case the name not only is becoming but actually becomes the thing.

These names will be found affixed to their respective canals in the map at the end of the book, a map made upon what is called Mercator's projection. Mercator's projection I take to have been primarily an invention of the devil, although commonly credited to Mercator. It is not simple to construct and for popular purposes is eminently deceitful. It is intended for those at sea, whom we pray for on Sundays. It is certainly calculated to put any one entirely at sea who attempts to learn geography by means of it. Its object is to enable such as wish to do so to sail upon rhumb lines, a rhumb line upon a sphere being one which never changes its direction, — one, for example, which runs perpetually north-east one quarter east, or south half west.

These lines, important in navigation, are in reality diminishing corkscrew-like spirals, but on this projection become straight lines which can be instantly laid down by rule and compass. To make such delineation possible it is necessary to distort the proportions of every part of the map, in increasing divergence toward the poles, with the lamentable result that in early life we all believed Nova Zembla to be a place as big as South America. Nevertheless Mercator's projection has certain advantages not so obvious to the uninitiated, nor requiring special mention here. In this connection it is only necessary to warn the reader, in the case of a geography with which he is not familiar, like that of Mars, to remember that the top and bottom of the map are drawn upon a scale three or four times as large as the middle; and, furthermore, that it is a consequence of Mercator's projection that arcs of great circles appear upon it, not as straight lines, but as curves always more or less concave to the equator. For relative size of the various features, he will find the twelve views from the globe accurate; but for the impressiveness of the great circle character of the canals, nothing short of a globe itself will give him adequate realization.

The map represents that part of the planet lying between latitudes 70° south and about 40° north. The south circumpolar regions will

be found in the chart of the south pole facing page 84. The northern ones were not presented to view at the last opposition, owing to the tilt toward us of the Martian south pole. No canals, therefore, north of about 40° north latitude were visible.

The list of the canals detected at Flagstaff is as follows:

Name.	No. of drawings in which it appears.	
Acalandrus	19	
Acampsis	7	
Acesines	19	
Achana	1	
Achates	9	
Achelous	20	
Acheron	11	
Acis	14	
Aeolus	13	
Aesis	23	
Aethiops	16	
Agathodaemon	127	
Alpheus	4	(Sus. 3)
Ambrosia	36	
Amenthes	26	
Amphrysus	1	
Amystis	15	
Anapus	7	
Antaeus	2	(Sus. 1)
Anubis	9	
Araxes	93	(Sus. 1)
Arges	2	
Arosis	8	
Arsanias	1	
Artanes	9	
Asopus	5	
Astaboras	7	
Astapus	29	
Atax	8	(Sus. 1)
Athesis	16	
Avernus	14	
Avus	8	
Axius	9	
Axon	2	
Bactrus	2	(Sus. 1)
Bactis	3	
Bathys	69	
Bautis		(Sus. 1)
Belus	3	
Boreas	11	
Boreosyrtis	4	
Brontes	38	
Caicus	8	
Cambyses	34	
Cantabras	7	
Carpis	3	
Casuentus	21	
Catarrhactes	3	
Cayster	3	
Centrites	27	
Cephissus	35	
Cerberus	44	(Sus. 1)

Name.	No. of drawings in which it appears.	Name.	No. of drawings in which it appears.
Cestrus	2	Gaesus	2
Chaboras	4	Galaesus	6
Chretes	14	Galaxias	28
Chrysas	6	Ganges	82
Chrysorrhoas	18	Ganymede	19
Cinyphus	14	Garrhuenus	12
Clitumnus	7	Gehon	11
Clodianus	1	Gigas	60 (Sus. 2)
Cophen	5	Glaucus	2
Coprates	41	Gorgon	33
Corax	33	Gyes	15
Cyaneus	6	Hades	22
Cyrus	3	Halys	4
Daemon	118	Harpasus	2
Daix	2 (Sus. 1)	Hebe	37
Daradax	6	Helisson	12
Dardanus	15	Heratemis	4
Dargamanes	20	Herculis Columnae	5
Deuteronilus	11	Hiddekel	18
Digentia	2	Hipparis	19
Dosaron	10	Hippus	13
Drahonus	5	Hyctanis	4
Elison	3	Hydaspes	1
Eosphorus	56 (Sus. 3)	Hydraotes	23
Erannoboas	17	Hydriacus	1
Erebus	21 (Sus. 1)	Hylias	7
Erinaeus	16	Hyllus	14
Erymanthus	21	Hyphasis	7 (Sus. 3)
Erynnis	3 (Sus. 1)	Hypsas	6
Eulaeus	1	Hyscus	13
Eumenides	103	Indus	10
Eunostos	12	Iris	7
Euphrates	36	Isis	5
Eurymedon	3	Jamuna	39
Eurypus	9	Jaxartes	23
Evenus	9	Labotas	8
Fortunae	10	Laestrygon	41

Name.	No. of drawings in which it appears.	Name.	No. of drawings in which it appears.
Leontes	2	Palamnus	9
Lethes	19	Parcae	19 (Sus. 1)
Liris	13	Peneus	3 (Sus. 2)
Maeander	6	Phasis	29
Magon	2	Phison	56
Malva	8	Protonilus	11
Margus	1	Psychrus	5
Medus	2	Pyriphlegethon	53 (Sus. 1)
Medusa	24	Scamander	21
Mogrus	2	Sesamus	7
Nectar	87	Simois	5
Neda	2	Sirenius	60
Nepenthes	21	Sitacus	3
Nereides	8	Steropes	46
Nestus	5	Styx	7
Neudrus	10	Surius	6
Nilokeras	16	Tartarus	42
Nilosyrtis	21	Tedanius	25
Nilus	6	Thermodon	2
Nymphaeus	4	Thyanis	1
Oceanus	37	Titan	38
Ochus	3	Tithonius	77
Opharus	13	Triton	8
Orcus	35	Tyndis	2
Orontes	33	Typhon	33
Orosines	29	Ulysses	33
Oxus	11	Uranius	8
Pactolus	11	Xanthus	12
Padargus	5		

The number of canals in this list is 183, and the number opposite each denotes the number of times each was seen and drawn; (Sus.) meaning, suspected in addition. There were in all, therefore, 3240 records made of them, not counting suspicions.

In the region visible at this opposition Schiaparelli has 79 canals. Of these 67 appear in the list given above. Of the other 12, the majority lie north of the equator, and therefore were likely not to be as visible as the rest at this last opposition, for two reasons connected with their position: first, on account of the tilt of the planet's axis at the time; and, secondly, because their northern situation would make their development late, as we shall shortly see. As no attempt was made to identify Schiaparelli's list, it will be seen how close is the accordance.

Of the 116 canals not down on Schiaparelli's map, 44 are canals in the dark regions and 72 canals in the light ones. Some of these, too, he saw prior to 1894. Both sets are, as a rule, more difficult of detection than the ones on his map; although there are some exceptions, attributable probably to difficulty of identification. The Brontes and Steropes, for example, might, unless well seen, be confounded with the Gigas on the one hand, or the Titan on the other. The most peculiar case, however, is the relative conspicuousness of the Ulysses.

III. ARTIFICIALITY.

It is patent that here are phenomena that are passing strange. To read their riddle we had best begin by excluding what they are not, as help towards deciphering what they are.

So far, we have regarded the canals only statically, so to speak; that is, we have sketched them as they would appear to any one who observed them in sufficiently steady air, once, and once only. But this is far from all that a systematic study of the lines will disclose. Before, however, entering upon this second phase of their description, we may pause to note how, even statically regarded, the aspect of the lines is enough to put to rest all the theories of purely natural causation that have so far been advanced to account for them. This negation is to be found in the supernaturally regular appearance of the system, upon three distinct counts: first, the straightness of the lines; second, their individually uniform width; and, third, their systematic radiation from special points.

On the first two counts we observe that the lines exceed in regularity any ordinary regularity of purely natural contrivance. Physical processes never, so far as we know, end in producing perfectly regular results; that is, results in which irregularity is not also discernible. Disagreement amid conformity is the inevitable outcome of the many factors simultaneously at work. From the orbits of the heavenly bodies to phyllotaxis and human features, this diversity in uniformity is apparent. As a rule, the divergences, though small, are quite perceptible;

that is, the lack of absolute uniformity is comparable to the uniformity itself, and not of the negligible second order of unimportance. In fact, it is by the very presence of uniformity and precision that we suspect things of artificiality. It was the mathematical shape of the Ohio mounds that suggested mound-builders; and so with the thousand objects of every-day life. Too great regularity is in itself the most suspicious of circumstances that some finite intelligence has been at work.

If it be asked how, in the case of a body so far off as Mars, we can assert sufficient precision to imply artificiality, the answer is twofold: first, that the better we see these lines, the more regular they look; and, second, that the eye is quicker to perceive irregularity than we commonly note. It is indeed surprising to find what small irregularities will shock the eye.

The third count is, if possible, yet more conclusive. That the lines form a system; that, instead of running anywhither, they join certain points to certain others, making thus, not a simple network, but one whose meshes connect centres directly with one another, — is striking at first sight, and loses none of its peculiarity on second thought. For the intrinsic improbability of such a state of things arising from purely natural causes becomes evident on a moment's consideration.

If lines be drawn haphazard over the surface of a globe, the chances are ever so many to one against more than two lines crossing each other at any point. Simple crossings of two lines will of course be common in proportion to the sum of an arithmetical progression; but that any three lines should contrive to cross at the same point would be a coincidence whose improbability only a mathematician can properly appreciate, so very great is it. If the lines were true lines, without breadth, the chances against such a coincidence would be infinite, that is, it would never happen; and, even had the lines some breadth, the chances would be great against a rendezvous. In other words, we might search in vain for a single instance of such encounter. On the surface of Mars, however, instead of searching in vain, we find the thing occurring *passim*; this *a priori* most improbable rendezvousing proving the rule, not the exception. Of the crossings that are best seen, all are meeting-places for more than two canals.

To any one who had not seen the canals, it might occur that something of the same improbability would be fulfilled by cracks radiating from centres of explosion or fissure. But such a supposition is at once negatived by the uniform breadth of the lines, a uniformity impossible in cracks, whose very mode of production necessi-

tates their being bigger at one end than at the other. We see examples of what might result from such action in the cracks that radiate from Tycho, in the Moon, or, as we now know from Professor W. H. Pickering's observations, from the craterlets about it. These cracks bear no resemblance whatever to the lines on Mars. They look like cracks; the lines on Mars do not. Indeed, it is safe to say that the Martian lines would never so much as suggest cracks to any one. Lastly, the different radiations fit into one another absolutely, an utter impossibility were they radiating rifts from different centres.

In the same way we may, while we are about it, show that the lines cannot be several other things which they have more or less gratuitously been taken to be. They cannot, for example, be rivers; for rivers could not be so obligingly of the same size at source and mouth, nor would they run from preference on arcs of great circles. To do so, practically invariably, would imply a devotion to pure mathematics not common in rivers. They may, in some few instances, be rectified rivers, which is quite another matter. Glaciation cracks are equally out of the question,—first, for the causes above mentioned touching cracks in general; and, second, because there is, unfortunately, no ice where they occur. Nor can the lines be fur-

rows ploughed by meteorites, — another ingenious suggestion, — since, in order to plough, invariably, a furrow straight from one centre to another, without either missing the mark or overshooting it, the visitant meteorite would have to be specially trained to the business.

Such are the chief purely natural theories of the lines, excluding the idea of canals, — theories advanced by persons who have not seen them. No one who has seen the lines *well* could advance them, inasmuch as they are not only disproved by consideration of the character of the lines, but instantly confuted by the mere look of them.

Schiaparelli supposes the canals to be canals, but of geologic construction. He suggests, however, no explanation of how this is possible; so that the suggestion is not, properly speaking, a theory. That eminent astronomer further says of the idea that they are the work of intelligent beings: "Io mi guarderò bene dal combattere questa supposizione, la quale nulla include d'impossibile." (I should carefully refrain from combating this supposition, which involves no impossibility.) In truth, no natural theory has yet been advanced which will explain these lines.

Their very aspect is such as to defy natural explanation, and to hint that in them we are regarding something other than the outcome of

purely natural causes. Indeed, such is the first impression upon getting a good view of them. How instant this inference is becomes patent from the way in which drawings of the canals are received by incredulously disposed persons. The straightness of the lines is unhesitatingly attributed to the draughtsman. Now this is a very telling point. For it is a case of the double-edged sword. Accusation of design, if it prove not to be due to the draughtsman, devolves *ipso facto* upon the canals.

IV. DEVELOPMENT

We have thus far considered the aspect of the canals viewed at any one time. We have now to consider an even more interesting branch of the subject, their consecutive appearances. The "open sesame" to our comprehension of the physical condition of Mars lies in systematic study of the appearances the planet's surface presents night after night and month after month. For that surface changes; and the order, extent, and character of its changes contain the key to their explanation. True as this is of the larger markings upon the disk, it is if anything more noticeably the case with the finer detail of the canals.

After the fundamental fact that such curious phenomena as the canals are visible, is the scarcely less curious one that they are not

always so. At times the canals are invisible, and this invisibility is real, not apparent; that is, it is not an invisibility due to distance or obscuration of any kind between us and them, but an actual invisibility due to the condition of the canal itself. With our present optical means, at certain seasons they cease to exist. For aught we can see, they simply are not there.

That distance is not responsible for the disappearance of the canals is shown by their relative conspicuousness at different times. It is not always when Mars is nearest to us that the canals are best seen. On the contrary, their visibility bears no relation to proximity. This is evidenced both by the changes in appearance of any one canal and by the changes in relative conspicuousness of different canals. Some instances of the metamorphosis will reveal this conclusively. For example, during the end of August and the beginning of September, at this last opposition, the canals about the Lake of the Sun were conspicuous, while the canals to the north of them were almost invisible. In November the relative intensities of the two sets had distinctly changed: the southern canals were much as before, but the northern ones had most perceptibly darkened.

Another instance of the same thing was shown in the case of the canals to the north of

the Sinus Titanum when compared with those about the Solis Lacus. In August the former were but faintly visible; in November they had become evident; and yet, during this interval, little change in conspicuousness had taken place in the canals in the Solis Lacus region.

With like disregard of the effect due to distance, the canals to the east of the Ganges showed better at the November presentation[1] of that region than they had at the October one, although the planet was actually farther off at the later date, in the proportion of 21 to 18.

A more striking instance of the irrelevancy of distance in the matter was observed in the same region by Schiaparelli in 1877. It is additionally interesting as practically dating his discovery of the canals. In early October of that year, on the evenings of the 2d and the 4th, he tells us, under excellent definition, and with the diameter of the planet's disk 21″ of arc, the continental region between the Pearl-Bearing Gulf and the Bay of the Dawn was quite uniformly, nakedly bright, and destitute

[1] A presentation of any part of the planet is the occasion when that part of the disk is turned toward the observer. Many causes combine to make the face presented each night vary, but the chief one is that the Earth rotates about forty-one minutes faster than Mars, and consequently gains a little less than ten degrees on him daily. After about thirty-seven days, therefore, the two planets again present the same face to each other at the same hour.

of suspicion of markings of any sort. A like state of things was the case with the same region at its next presentation, on the 7th of November. Four months later, when the diameter of the disk had been reduced by distance to 5″.7, or, in other words, when the planet had receded to four times its previous distance from the earth, the canal called the Indus appeared, perfectly visible, in the region mentioned. At the next opposition, in 1881, similar effects occurred; the canals in this region remaining obstinately invisible while the planet was near the earth, and then coming out conspicuously when it had gone farther away. Distance, therefore, is not, with the canals, the great obliterator.

As to their veiling by Martian cloud or mist, there is no evidence of any such obscuration. The coast line of the dark areas appears as clear-cut when the canals are invisible as when they become conspicuous.

A canal, then, alters in visibility for some reason connected with itself. It grows into recognition from intrinsic cause. But, during all its metamorphoses, in one thing, and in one thing only, it remains fixed, — in position. Temporary in appearance, the canals are apparently permanent in place. Not only do they not change in position during one opposition; they seem not to do so from one opposition to

another. The canals I have observed this year agree fairly within the errors of observation with those figured on Schiaparelli's chart.

The fact that in all cases they do not absolutely agree with his is the very best of proofs that they are substantially the same; for such slight discordance proves the absence of conscious psychic reproduction. It confirms by not conforming.

As, in observations of minute detail, the psychic element insensibly creeps in, it will be well to consider it for a moment. An idea is a force, a mode of motion, which, unless obstructed by other ideas, instantly and inevitably produces its effect upon whatever mind it may chance to impinge, just as light or electricity or any other mode of motion does, according to its kind. An easy instance of this can be got by asserting at dinner, before a company of connoisseurs, that the wine is slightly corked. Every one not actuated by a spirit of contradiction will at once perceive that it is so, and will continue to believe it, in many cases, after it is abundantly disproved. This is what takes place in the normal, unbiased — that is, so far as this idea goes — vacant mind. But minds have their familiar ideas, which an incoming idea is pretty sure to rouse, and these react to some extent upon the stranger, and color it with something of their own complexion. If we expect to meet

a certain person, an approaching figure will most deceitfully take on his garb. The mere idea of a man walking finds the expectation ready instinctively to endow it with the attributes of our friend. But this may happen truly as well as falsely. The expert sees what the tyro misses, not from better eyesight but from better mechanism in the higher centres. A very slight hint from the eye goes a long way in the brain of the one; no distance at all in the brain of the other.

Our senses are our avenues of approach from the outer world. Messages from them are therefore usually and rightly attributed to stimuli from without. But it is possible for these messages to be tampered with at any stage of their journey. It is even possible for them to be started in some other part of the brain, travel down to the lower centres and be sent up from them to the higher ones, indistinguishable from *bona fide* messages from without. Bright points in the sky or a blow on the head will equally cause one to see stars. In the first case the eyes were duly affected from without; in the second, the nerves were tapped to the same effect in mid-route; but in each case the subsequent current travels to the higher centres apparently as authentic the one as the other.

Hallucinations of one sort and another occur

in this way. More common, however, are unconscious changes in an originally quite veridic message. We easily see what we expect to see, but with great difficulty what we do not. This may be due to individual idiosyncrasy, or it may be due to a prevailing idea of the time, affecting people generally, in which we unwittingly share. Fashion is as potent here as elsewhere. The very same cause will show us at one time what we remain callously blind to at another. A few years ago it was the fashion not to see the canals of Mars, and nobody except Schiaparelli did. Now the fashion has begun to set the other way, and we are beginning to have presented suspiciously accurate fac-similes of Schiaparelli's observations.

In any observation, the observer is likely to be unconsciously affected in some way or other *pro* or *con*, which, from the fact that he is unconscious of it, he is unable to find out. The only sure test, therefore, is the seeing what no one else has seen, the discovery of new detail. Next to that is not too close an agreement with others. Inevitable errors of observation, to say nothing of times and seasons, distance and tilt, are certain to produce differences, of which one has ample proof in comparing his own drawings with one another. Even too close agreement with one's self is suspicious. In the matter of fine detail, absolute agreement is therefore neither to be expected nor to be desired.

All the changes so far observed on the planet's disk are, I believe, capable of explanation either by errors of observation or by seasonal change. For, as is the case with the Earth, not only must vegetation produce different appearances according to the time of year, but its aspects would vary somewhat as between year and year. This seasonal variation would affect not only the visibility of any one canal at any particular time, but might easily produce apparent alterations of place; visibility of one canal, combined with visibility or invisibility in its neighbors, being competent to simulate any shift.

The Araxes is a case in point. On Schiaparelli's chart there is but one original Araxes and one great and only Phasis. But it turns out that these do not possess the land all to themselves. No less than five canals traversing the region, including the Phasis itself, were visible this year at Flagstaff, and I have no doubt there are plenty of others waiting to be discovered. These cross one another at all sorts of angles. Unconscious combination of them is quite competent to give a turn to the Araxes one way or the other, and make it curved or straight at pleasure.

Unchangeable, apparently, in position, the canals are otherwise among the most changeable features of the Martian disk. From being

invisible, they emerge gradually, for some reason inherent in themselves, into conspicuousness. In short, phenomenally at least, they grow. The order of their coming carries with it a presumption of cause, for it synchronizes with the change in the Martian seasons. Their first appearance is a matter of the Martian time of year.

To start with, the visible development of the canal system follows the melting of the polar snows. Not until such melting has progressed pretty far do any of the canals, it would seem, become perceptible.

Secondly, when they do appear, it is, in the case of the southern hemisphere, the most southern ones that become visible first. Last June, when the canals were first seen, those about the Lake of the Sun and the Phoenix Lake were easier to make out than any of the others. Now, this region is the part of the reddish-ochre continent, as we may call it, that lies nearest the south pole. It extends into the blue-green regions as far south as 40° of south latitude. Nor do any so-called islands — that is, smaller reddish-ochre areas — stand between it and the pole. It lies first exposed, therefore, to any water descending toward the equator from the melting of the polar cap.

Having once become visible, these canals remained so, becoming more and more conspicu-

Plate XIX

P. L.

LACUS PHOENICIS
November, 1894

Lowell Obs
Flagstaff, A

ous as the season advanced. By August they had darkened very perceptibly. As yet, those in other parts of the planet were scarcely more visible than they had been two months before. Gradually, however, others became evident, farther and farther north, till by October all the canals bordering the north coast of the dark regions were recognizable; after which the latter, in their turn, proceeded to darken, — a state of things which continued up to the close of observations. (Plates XXI. and XXII.)

The order in which the canals came out hinted that two factors were operative to the result, — latitude and proximity to the dark regions. Other things equal, the most southern ones showed first; beginning with the Solis Lacus region, and continuing with those about the Sea of the Sirens and the Titan Gulf, and so northward down the disk. Other things were not, however, always equal in the way of topographical position. Notably was this the case with the areas to the west of the Syrtis Major, which developed canals earlier than their latitudes would warrant. Now, to the Syrtis Major descend from the pole the great straits spoken of before, which, although not in their entirety water, are probably lands fertilized by a thread of water running through them. They connect the polar sea with the Syrtis Major in a tolerably straight line.

The direction of the canal also affects its time of appearance, though to a less extent. Canals running north and south, such as the Gorgon, the Titan, the Brontes, and the like, became visible, as a rule, before those running east and west. Especially was this noticeable in the more northern portions of the disk. Time of appearance was evidently a question of latitude tempered by ease of communication.

After the canals had appeared, their relative intensities changed with time, and the change followed the same order in which the initial change from invisibility to visibility had taken place. A like metamorphosis happened to each in turn from south to north, in accordance with, and continuance of, the seasonal change that affected all the blue-green areas.

To account for these phenomena, the explanation that at once suggests itself is, that a direct transference of water takes place over the face of the planet, and that the canals are so many waterways. This explanation labors under the difficulty of explaining nothing. There are two other objections to it: an insufficiency of water, and a superabundance of time, for some months elapsed between the apparent departure of the water from the pole and its apparent advent in the equatorial regions; furthermore, each canal did not darken all at once, but gradually. We must therefore seek some

explanation which accounts for this delay. Now, when we do so, we find that the explanation advanced above for the blue-green areas explains also the canals, namely, that what we see in both is, not water, but vegetation; for if the darkening be due to vegetation, time must elapse between the advent of the water and its perceptible effects,—time sufficient for the flora to sprout. If, therefore, we suppose what we call a canal to be, not the canal proper, but the vegetation along its banks, the observed phenomena stand accounted for. This suggestion was first made some years ago by Professor W. H. Pickering.

That what we see is not the canal proper, but the line of land it irrigates, disposes incidentally of the difficulty of conceiving a canal several miles wide. On the other hand, a narrow, fertilized strip of country is what we should expect to find; for, as we have seen, the general physical condition of the planet leads us to the conception, not of canals constructed for waterways, —like our Suez Canal,—but of canals dug for irrigation purposes. We cannot, of course, be sure that such is their character, appearances being often highly deceitful; we can only say that, so far, the supposition best explains what we see. Further details of their development point to this same conclusion.

In emerging from invisibility into evidence,

the canals first make themselves suspected, rather than seen, as broad, faint streaks smooching the disk. Such effect, however, seems to be an optical illusion, due to poor air and the difficulty inherent in detecting fine detail; for on improvement in the seeing I have observed these broad streaks contract to fine lines, not sensibly different in width from what they eventually become.

The parts of the canals which are nearest the dark areas show first, the line extending sometimes for a few hundred miles into the continent, sometimes for a thousand or more; then, in course of time, the canal becomes evident in its entirety. Complete visibility takes place soon after the canal has once begun to show, although it show but faintly throughout.

This tendency to being seen *in toto* is more strikingly displayed after a canal has attained its development. It is then not commonly seen in part. Either it is not seen at all, owing to the seeing not being good enough, or it is visible throughout its length from one junction to another.

Apart from their extension, the growth of the canals consists chiefly in depth of tint. They darken rather than broaden, — a fact which tends to corroborate their vegetal character; for that long tracts of country should be thus simultaneously flooded all over to a gradually

deepening extent is highly unlikely, while a growth of vegetation would deepen in appearance in precisely the way in which the darkening takes place.

As for color, the lines would seem to be of the same tint as the blue-green areas. But, owing to their narrowness, this is only an inference. I have never chanced to see them of distinctive color.

At this point it is probable that a certain obstacle to such wholesale construction of canals, however, will arise in the mind of the reader, namely, the thought of mountains; for mountains are by nature antagonistic to canals. Only the Czar of all the Russias — if we are to credit the account of the building of the Moscow railway — would be capable of running a canal regardless of topography. Nor will the doings at our own antipodes help us to conceive such construction; for though the Japanese irrigate hillsides, the water in the case comes from slopes higher yet, whereas on Mars it does not.

Indeed, for the lines to contain canals we must suppose either that mountains prove no obstacles to the Martians, or else that there are practically no mountains on Mars. For the system seems sublimely superior to possible obstructions in the way; the lines running, apparently, not where they may, but where they choose. The Eumenides-Orcus, for example,

pursues the even tenor of its unswerving course for nearly 3500 miles. Now, it might be possible so to select one's country that one canal should be able to do this; but that every canal should be straight, and many of them fairly comparable with the Eumenides-Orcus in length, seems to be beyond the possibility of contrivance.

In this dilemma between mountains on the one hand and canals on the other, a certain class of observations most opportunely comes to our aid; for, from observations which have nothing to do with the lines, it turns out that the surface of the planet is, in truth, most surprisingly flat. How this is known will most easily be understood from a word or two upon the manner in which astronomers have learnt the height of the mountains in the Moon.

The heights of the lunar mountains are found from measuring the lengths of the shadows they cast. As the Moon makes her circuit of the Earth, a varying amount of her illuminated surface is presented to our view. From a slender sickle she grows to full moon, and then diminishes again to a crescent. The illuminated portion is bounded by a semicircle on the one side, and by a semi-ellipse on the other. The semicircle is called her limb, the semi-ellipse her terminator. The former is the edge we see because we can see no farther; the latter, the

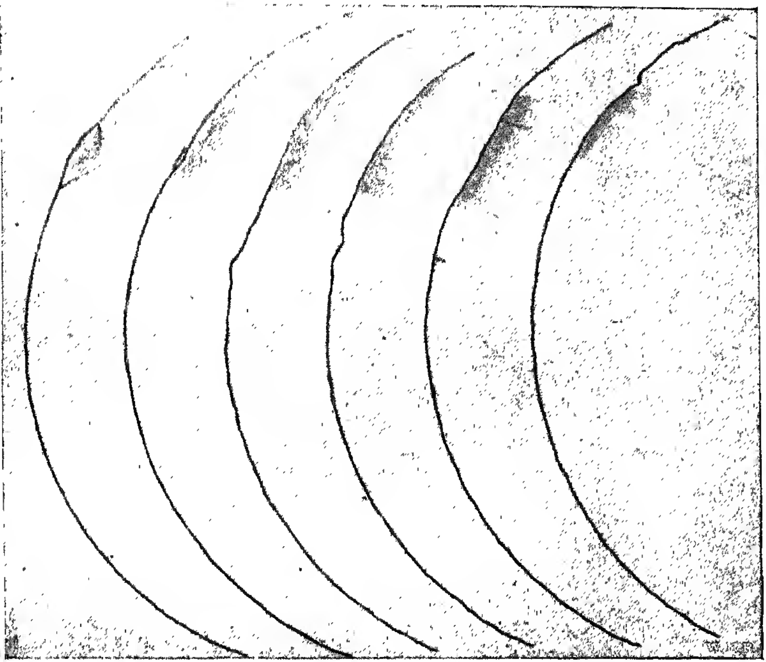
line upon her surfaee where the sun is just rising or setting. Now, as we know, the shadows cast at sunrise or sunset are very long, much longer than the objeets that cast them are high. This is due to the obliquity at which the light strikes them; the same effect being produced by any sufficiently oblique light, such as an eleetric light at a distanee. Impereeptible in themselves, the heights beeome pereeptible by their shadows. A road illuminated by a distant are light gives us a startling instanee of this; the smooth surface taking on from its shadows the look of a ploughed field.

It is this indirect kind of magnification that enables astronomers to measure the lunar mountains, and even renders such vicariously visible to the naked eye. Every one has notieed how ragged and irregular the inner edge of the Moon looks, while her outer edge seems perfectly smooth. In one place it will appear to project beyond the perfeet ellipse, in another to reeede from it. The first effect is due to mountain tops catching the sun's rays before the plains about them; the other, to mountain tops further advaneed into the lunar day, whose shadows still shroud the valleys at their feet. Yet the elevations and depressions thus rendered so notieeable vanish in profile on the limb.

Much as we see the Moon with the naked eye do we see Mars with the telescope. Mars being

outside of us with regard to the Sun, we never see him less than half illumined, but we do see him with a disk that lacks of being round, — about what the Moon shows us when two days off from full. It is when he is in quadrature — that is, a quarter way round the celestial circle from the Sun — that he shows thus, and we see him then with the telescope at closer range than we ever see the Moon without it. So observed we notice at once that his terminator, or inner edge, presents a very different appearance from the lunar one. Instead of looking like a saw, it looks comparatively smooth, like a knife. From this we know that, relatively to his size, he has no elevations or depressions upon his surface comparable to the lunar peaks and craters.

His terminator, however, is not absolutely perfect. Irregularities are to be detected in it, although much less pronounced than those of the Moon. His irregularities are of two kinds. The first, and by all odds the commonest phenomenon, consists in showing himself on occasions surprisingly flat; not in this case an inferable flatness, but a perfectly apparent one. In other words, his terminator does not show as a semi-ellipse, but as an irregular polygon. It looks as if in places the rind had been pared off. The peel thus taken from him, so to speak, is from twenty to forty degrees wide, according to the particular part of his surface that shows upon the terminator at the time.



13*h* 24*m* 13*h* 30*m* 16*h* 15*m* 16*h* 23*m* 16*h* 56*m* 17*h* 30*m*

TERMINATOR VIEWS

BY PROF. W. H. PICKERING

August 24, 1894

A series of unusually marked elevations and depressions upon the terminator at the above hours

LOWELL OBSERVATO
Flagstaff, A. T. 18

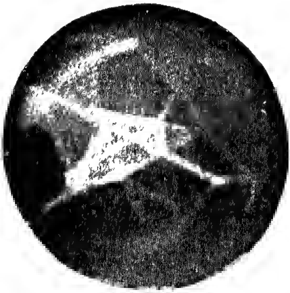


FIG. I. Nov. 26. Long. cent. 314°
Seeing 2 to 6. Diam. 15″.8

FIG. II. Oct. 9. Long. cent. 45°
Seeing 5 to 9. Diam. 21″.7

FIG. III. Feb. 8. Long. cent. 295°
Seeing 2 to 5. Diam. 7″.5

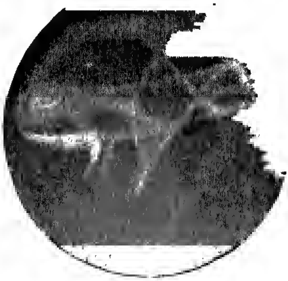


FIG. IV. Nov. 23. Long. cent. 31°
Seeing 2 to 7. Diam. 16″.3

FIG. V. March 16. Long. cent. 312°
Seeing 2 to 8. Diam. 6″.4

FIG. VI. March 9. Long. cent. 26°
Seeing 3 to 7. Diam. 6″.6

DRAWINGS AFTER OPPOSITION [EXCEPT ONE]
BY A. E. DOUGLASS

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

The other kind is short and sharp. Now it will be remembered that we considered both kinds under the question of atmosphere, and we found both to be explicable as the effect of clouds, but not the effect of mountains. We may therefore feel tolerably certain that Mars is a flat world; devoid, as we may note incidentally, of summer resorts, since it possesses, apparently, neither seas nor hills. To canals we will now return.

The canals so far described all lie in the bright reddish-ochre portions of the disk,—those parts which bear every appearance of being desert. But Mr. Douglass has made the discovery that they are not the only part of the planet thus privileged. He finds, in the very midst of the dark regions themselves, straight, dark streaks not unlike in look to the canals, and still more resembling them in the systematic manner in which they run. For they reproduce the same rectilinear arrangement that is so striking a characteristic of their bright-area fellows. He has succeeded, indeed, in thus triangulating all the more important dark areas.

Now this is a very interesting discovery, from several points of view. In the first place, it proves another tell-tale circumstance as to the true character of the so-called seas; for that the seas should be traversed by permanent dark lines is incompatible with a fluid constitution. But

the lines are even more suggestive from a positive than they are from a negative standpoint. For they make continuations of the lines in the bright regions, showing that the two are causally connected, and affording strong presumption that this causal relation is the very one demanded by the theory of irrigation. For if the canals in the bright regions be strips of vegetation irrigated by a canal (too narrow to be itself visible at our distance), and there be a scarcity of water upon the surface of the planet, the necessary water would have to be conducted to the mouths of the canals across the more permanent areas of vegetation, thus causing bands of denser verdure athwart them, which we should see as dark lines upon the less dark background. Indeed, it is exactly what we should expect to find if the theory here advanced be true. For it is the very next logical step in that theory made visible. If the canals in the bright regions are to be fed from the melting of the polar cap, it is altogether likely that they would be connected with it by other canals running through the dark regions. We might, therefore, expect to see lines in the dark regions not unlike the lines in the bright ones, and if these lines were of the same character as those in the bright regions they would betray this character by connecting directly with them. Now this is precisely what he finds the two sets

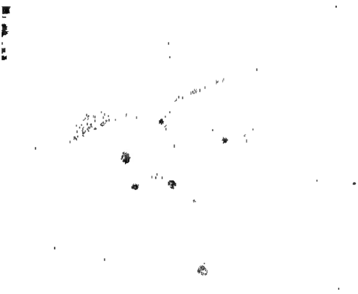


FIG. I. Nov. 14. Long. cent. 114°
Seeing 4 to 8. Diam. 17″.9

FIG. II. Nov. 5. Long. cent. 184°
Seeing 1 to 3. Diam. 19″.5

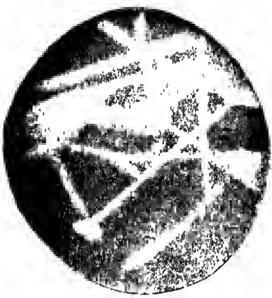


FIG. III. Dec. 17. Long. cent. 100°
Seeing 2 to 6. Diam. 12″.4

FIG. IV. Dec. 1. Long. cent. 246°
Seeing 2 to 4. Diam. 14″.9

FIG. V. Feb. 21. Long. cent. 193°
Seeing 2 to 4. Diam. 7″.4

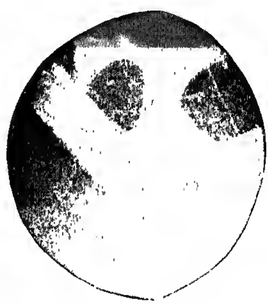


FIG. VI. Jan. 8. Long. cent. 266°
Seeing 1 to 3. Diam. 9″.9

DRAWINGS AFTER OPPOSITION
BY A. E. DOUGLASS

LOWELL OBSERVATORY
Flagstaff, A. T. 1895

of lines do. His canals in the dark regions end at the very points at which the others begin, and they do this invariably. There is no canal in the dark areas which does not so connect with one in the bright regions.

Finally, some of the most southern appear to run tolerably straight toward the pole; but of the plan underlying the whole system of Martian canals we cannot at present predicate details, as, though the system instantly suggests plan, it suggests a plan that does not instantly commend itself to human comprehension.

Mr. Douglass finds 44 of these canals, not including the straits between the islands, as is shown in the following list: —

Name.	No. of drawings in which it appears.	Name.	No. of drawings in which it appears.
Acalandrus	19	Dosaron	10
Acesines	19	Drahonus	5
Acis	14	Erannoboas	17
Aeolus	13	Erymanthus	21
Amphrysus	1	Eurypus	9
Athesis	16	Gaesus	2
Caicus	8	Galaesus	6
Carpis	3	Garrhuenus	12
Casuentus	21	Harpasus	2
Cayster	3	Helisson	12
Cestrus	2	Heratemis	4
Chaboras	4	Hipparis	19
Cinyphus	14	Hippus	13
Cyaneus	6	Hyctanis	4
Cyrus	3	Hydriacus	1
Dargamanes	20	Hylias	7
Digentia	2	Hyllus	14

Name.	No. of drawings in which it appears.	Name.	No. of drawings in which it appears.
Leontes	2	Oceanus	37
Malva	8	Opharus	13
Mogrus	2	Orosines	29
Nestus	5	Padargus	5
Neudrus	10	Tedanius	25

All these run either through the dark regions proper, or through those chiaro-oscuro areas, such as Deucalionis Regio and Pyrrhae Regio, which have hitherto been thought to be amphibious, and are probably half desert. They connect on the one hand with the canals in the bright regions, and on the other with the straits between the so-called islands, — such strait-canals as Scamander, Xanthus, and the like, if we may so designate without misunderstanding what is probably not water at all.

It is interesting thus to forestall objection about a missing link by discovering that link thus early.

Before passing on to certain other phenomena connected with the canals of like significance, we may note here an *obiter dictum* of the irrigation theory of some slight corroborative worth; for, if a theory be correct, it will not only fit all the facts, but at times go out of its way to answer questions. Such the present one seems to do. If the seas be seas, and the canals canals, we stand confronted by the problem how to make fresh-water canals flow out of

salt-water seas. General considerations warrant us in believing that the Martian seas, like our own, would contain salts in solution, while irrigation ditches, there as here, should flow fresh water to be most effective, and we seem committed to the erection of distilleries upon a gigantic scale. But if, on the contrary, the seas be not seas, but areas of vegetation, the difficulty vanishes at once; for, if the planet be dependent upon the melting of its polar snows for its spring freshet, the water thus produced must necessarily be fresh, and the canals be directly provided with the water they want. The polar sea is a temporary body of water, formed anew each year, not a permanent ocean; consequently there is no chance for saline matter to collect in it. From it, therefore, fresh water flows, and, like our rivers, gathers nothing to speak of in the way of salt before it is drawn off into the canals.

We now come to some phenomena connected with the canals, of the utmost suggestiveness. I have said that the junctions held, in a twofold way, the key to the unlocking of the mystery of the canals: in the first place, in the fact that such junctions exist. The second and more important reason remains to be given, for it consists in what we find at those junctions. This we shall see in the next chapter.

V

OASES

I. SPOTS IN THE LIGHT REGIONS

SUGGESTIVE of irrigation as the strange network of lines that covers the surface of Mars appears to be, the suggestion takes on more definite shape yet with the last addition to our knowledge of the planet's surface detail, — the recognition of a singularly correlated system of spots.

The canals, as we have seen, are very remarkably attached to one another. Indeed, the manner with which they manage to combine undeviating direction with meetings by the way grows more and more marvelous, the more one studies it. The meeting-places, or junctions, are evidently for something in the constitution of the canals. The crossings, in fact, seem to be the end and aim of the whole system; the canals, but means to that end. So much is at once inferable from the great intrinsic improbability that such crossings can be due to chance.

This inference receives, apparently, striking corroboration when the planet is more minutely

scanned. For there turns out to be something at these junctions. This something shows itself as a round or oval spot. To such spot, planted there in the midst of the desert at the junction, do the neighboring canals converge.

Dotted all over the reddish-ochre ground of the desert stretches of the planet, the so-called continents of Mars, are an innumerable number of dark circular or oval spots. They appear, furthermore, always in intimate association with the canals. They constitute so many hubs to which the canals make spokes. These spots, together with the canals that lead to them, are the only markings to be seen anywhere on the continental regions. Otherwise the great reddish-ochre areas are absolutely bare; of that pale fire-opal hue which marks our own deserts seen from far.

That these two things, — straight lines and roundish spots, — should, with our present telescopic means, be the sole markings to appear on the vast desert regions of the planet is suggestive in itself.

Another significant fact as to the character of either marking is the manifest association of the two. In spite of the great number of the spots, not one of them stands isolate. There is not a single instance of a spot that is not connected by a canal to the rest of the dark areas. This remarkable inability to stand alone shows

that the spots and the canals are not unrelated phenomena, for were there no tie between them they must occasionally exist apart.

Nor is this all. There is, apparently, no spot that is not joined to the rest of the system, not only by a canal, but by more than one; for though some spots, such as the Fountain of Youth, have appeared at first to be provided with but a single canal connection, later observation has revealed concurrence in the case. The spots are, therefore, not only part and parcel of the canal system, but terminal phenomena of the same.

In the first place, as I have said, there appears to be no spot that has not two or more canals running to it; in the second place, I find, reversely, that apparently no canal junction is without its spot. Such association is a most tell-tale circumstance. I believe the rule to have no exception. The more prominent junctions all show spots; and with regard to the less conspicuous ones, it is to be remembered that, as the canals are more easy to make out than the spots, the relative invisibility of the latter is to be expected. From which it would seem that the spots are fundamental features of the junctions, and that for a junction to be spotless is, from its very nature, an impossibility.

Next to their regularity of position is to be remarked their regularity of form. Their typi-

cal shape seems to be circular; for the better the atmosphere, the rounder they look. Under poor seeing they show as irregular patches smooching the disk, much as the canals themselves show as streaks; the spots differing from the canals in being thicker and not so long. As the seeing improves, the patches differentiate themselves into round dots and connecting lines. Such is the shape of the spots associated with single canals; that is, canals not double. In the case of the double canals, the spots look like rectangles with the corners rounded off. One of the most striking of all of them is the Trivium Charontis, which is nearly square.

Now it will be noticed that these shapes are as unnatural as they are definite, and that they all agree in one peculiarity: they are all convex, not concave, to the entering canals. They are not, therefore, mere enlargements of the canals, due to natural causes; for, were the spots enlargements of the canals, at their crossing-points they should be more or less star-shaped, or concave to the canals, whereas they are round, or roundish rectangles, — that is, convex to the same. Such convexity negatives, at the outset, their being purely natural outgrowths of the canals.

The majority of the spots are from 120 to 150 miles in diameter; thus presenting a certain uniformity in size as well as in shape.

There are also smaller ones, not more than 75 miles across, or less.

To the spot category belong, apparently, all the markings other than canals to be seen anywhere on the continental deserts of the planet, from the great Lake of the Sun, which is 540 miles long by 300 miles broad, to the tiny Fountain of Youth, which is barely distinguishable as a dot. That all are fundamentally of a kind is hinted at by their shape and emphasized by their character, a point to which we shall now come.

To this end, we will start with an account of where and how they begin to show; for, like the canals, they are not permanent markings, but temporary phenomena. It is in the region about the Solis Lacus that they appear first. The Solis Lacus, or Lake of the Sun, is perhaps the most striking marking on Mars. It is an oval spot in lat. 28° S., with its greater diameter nearly perpendicular to the meridians, and encircled by an elliptical ring of reddish-ochre land, which in turn is bordered on the south by the blue-green regions of the south temperate zone. The whole configuration is such as to simulate a gigantic eye which uncannily turns round upon one as the planet slowly revolves. It is so conspicuous a feature of the disk that it has been recognized for a great many years. The resemblance to an eye is further borne out

by a cordon of canals that surround it on the north. Upon this cordon, composed of the Araxes, the Daemon, and the Agathodæmon, are beaded a number of spots, two of them, the Phoenix and the Tithonius lakes, being conspicuously prominent. Closer scrutiny reveals several more of the same sort, only smaller. These are all interconnected by a network of canals. Now just as it is in this region that the canals first show, so likewise is it here that the spots first make their appearance.

Although it was here that at this last opposition the spots were first seen, it was not here that their character and purpose became apparent. It was not until later in the season, when the Eumenides-Orcus began to give evidence of being yet more peculiarly beaded, that the true nature of the spots suggested itself to me.

The Eumenides-Orcus is a very long and important canal, connecting the Phoenix Lake with the Trivium Charontis. It is so long — 3,540 miles from one end of it to the other — that, although it starts in lat. 16° N. and ends in lat. 12° S., it belts the disk not many degrees inclined to the equator. For a great distance it runs parallel to the northern coast of the Sea of the Sirens. From this coast several canals strike down to it; some stopping at it, others continuing on down the disk. Especially is the western end of the sea, called the Gulf of the

Titans, a point of departure for canals; no less than six of them, and doubtless more, leaving the gulf in variously radiating directions. At the place where these canals severally cross the Eumenides-Orcus, I began in November to see spots. I also saw others along the Pyriphlegethon, an important canal leading in a more northerly direction from the Phoenix Lake; along the Gigas, a great canal running from the Gulf of the Titans all the way to the Lake of the Moon; and along other canals in the same region. I then noticed that the spots to the north of the Solis Lacus region had darkened, since August, relatively to the more southern ones. In short, I became aware both of a great increase in the number of spots, and of an increase in tint in the spots previously seen.

It was apparent that the spots were part and parcel of the canal system, and that in the matter of varying visibility they took after the canals, — chronologically, very closely after them; for a comparison of the two leads me to believe that the spots make their appearance subsequent, although but little subsequent, to the canals which conduct to them.

Furthermore, the spots, like the canals, grow in conspicuousness with time. Now, when we consider that nothing, practically, has changed between us and them in the interval; that

there has been no symptom of cloud or other obscuration, before or after, over the place where they eventually appear, — we are led to the conclusion that, like the canals, they grow.

Indeed, in the history of their development the two features seem quite similar. Both grow, and both follow the same order and method in their growth. Both are affected by one progressive change that sweeps over the face of the planet from the pole to the equator, and then from the equator toward the other pole. In the case of the southern hemisphere, it is, as we have just seen, the most southern spots, like the most southern canals, that appear first after the melting of the polar snows. Then gradually others begin to show farther and farther north. The quickening of the spots, like the quickening of the canals, is a seasonal affair. But there is more in it than this. It takes place in a manner to imply that something more immediate than the change in the seasons is concerned in it; immediate not in time, but in relation to the result. A comparison of the behavior of three spots — the Phoenix Lake, Ceraunius, the spot at the junction of the Iris and the Gigas, and the Cyane Fons, a spot where the Steropes, a newly found canal, and the Nilus meet — will serve to point out what this something is. The Phoenix Lake lies in lat. 17° S., Ceraunius in lat. 12° N., and

the Cyane Fons in lat. 28° N. In August of last year, the first of these markings was very conspicuous, the second but moderately so, while the third was barely discernible. By November, the Phoenix Lake had become less salient, Ceraunius relatively more so, and the Cyane Fons nearly as evident as Ceraunius had formerly been. In the Martian calendar, the August observation corresponded to our 20th of June, the November one to our 1st of August. All three spots were practically within the equatorial regions. Now, on the Earth, no such marked progression in seasonal change occurs within the tropics. With us, it is to all intents and purposes equally green there the year through. On Mars it is not. Clearly, some more definite factor than the seasons enters into the matter upon our neighbor world.

That this factor is water seems, from the behavior of the blue-green areas generally, to be pretty certain. But just as the so-called seas are undoubtedly not seas, nor the canals waterways, so the spots are not lakes. Their mode of growth, so far as it may be discerned, confirms this conclusion. Apparently, it is not so much by an increase in size as by a deepening in tint that they gradually become recognizable. They start, it would seem, as big as they are to be, but faint in tone, premonitory shades of their future selves. They then proceed to

substantialize by darkening in tint throughout. Now, to deepen thus in color with one consent all over would be a peculiar thing for a lake to do. For had the lake appreciable depth to start with, it should always be visible; and had it not, its bed would have to be phenomenally level to permit of its being all flooded at once. If, however, the spots be not bodies of water, but areas of verdure, their deepening in tint throughout is perfectly explicable, since the darkening would be the natural result of a simultaneous growth of vegetation. This inference is further borne out by the fact that to the spot class belong unquestionably those larger oval markings of which the Lake of the Sun is the most conspicuous example. For both are associated in precisely the same manner with the canal system. Each spot is a centre of canal connections in exactly the way in which the Solis Lacus or the Phoenix Lake itself is. But the light coming from the Solis Lacus and the Phoenix Lake showed, in Professor W. H. Pickering's observations, no sign of polarization such as a sheet of water should show, and such as the polar sea actually did show.

When we put all these phenomena together, —the presence of the spots at the junctions of the canals, their strangely systematic shapes, their seasonal darkening, and, last but not least,

the resemblance of the great continental regions of Mars to the deserts of the earth, — a solution of their character suggests itself at once; to wit, that they are oases in the midst of that desert, and oases not wholly innocent of design; for, in number, position, shape, and behavior, the oases turn out as typical and peculiar a feature of Mars as the canals themselves.

Each phenomenon is highly suggestive considered alone, but each acquires still greater significance from its association with the other; for here in the oases we have an end and object for the existence of canals, and the most natural one in the world, namely, that the canals are constructed for the express purpose of fertilizing the oases. Thus the mysterious rendezvousing of the canals at these special points is at once explicable. The canals rendezvous so entirely in defiance of the doctrine of chances because they were constructed to that end. They are not purely natural developments, but cases of assisted nature, just as they look to be at first sight. This, at least, is the only explanation that fully accounts for the facts. Of course all such evidence of design may be purely fortuitous, with about as much probability, as it has happily been put, as that a chance collection of numbers should take the form of the multiplication table.

In addition to this general dovetailing of

detail to one conclusion is to be noticed the strangely economic character of both the canals and the oases in the matter of form. That the lines should follow arcs of great circles, whatever their direction, is as unnatural from a natural standpoint as it would be natural from an artificial one; for the arc of a great circle is the shortest distance from one point upon the surface of a sphere to another. It would, therefore, if topographically possible, be the course to take to conduct water, with the least expenditure of time or trouble, from the one to the other.

The circular shape of the oases is as directly economic as is the straightness of the canals; for the circle is the figure which incloses the maximum area for the minimum average distance from its centre to any point situated within it. In consequence, if a certain amount of country were to be irrigated, intelligence would suggest the circular form in preference to all others, in order thus to cover the greatest space with the least labor.

Following is the list of the oases so far discovered: —

Acherusia Palus
Aganippe Fons
Alcyonia
Ammonium
Aponi Fons
Aquae Apollinares
Aquae Calidae
Arachoti Fons
Arduenna
Arethusa Fons

Arsia Silva
Arsine
Augila
Bandusiae Fons
Biblis Fons
Castalia Fons
Ceraunius
Clepsydra Fons
Cyane Fons
Ferentinae Lucus
Fons Juventae
Gallinaria Silva
Hercynia Silva
Hibe
Hippocrene Fons
Hipponitis Palus
Hypelaeus
Labeatis Lacus
Lacus Ismenius
Lacus Lunae
Lacus Phoenicis
Lerne
Lucrinus Lacus
Lucus Angitiae
Lucus Feronia
Lucus Maricae
Maeisia Silva
Mapharitis
Mariotis
Meroe
Messeis Fons
Nitriae
Nodus Gordii
Pallas Lacus
Propontis
Serapium
Sirbonis Lacus
Solis Fons
Solis Lacus
Tithonius Lacus
Trinythios
Trivium Charontis
Utopia

II. DOUBLE CANALS

Even more markedly unnatural is another phenomenon of this most phenomenal system, of which almost every one has heard, and which almost nobody has seen, — the double canals.

To see them, however, all that is needed is a sufficiently steady air, a sufficiently attentive observer, and the suitable season of the Martian year. When these conditions are observed, the sight may be seen without difficulty, and is every whit as strange as Schiaparelli, who first saw it, has described it.

So far as the observer is concerned, what occurs is this: Upon a part of the disk where up to that time a single canal has been visible, of a sudden, some night, in place of the single canals he perceives twin canals,—as like, indeed, as twins, if not more so, similar both in character and in inclination, running side by side the whole length of the original canal, usually for upwards of a thousand miles, of the same size throughout, and absolutely parallel to each other. The pair may best be likened to the twin rails of a railroad track. The regularity of the thing is startling.

In good air the phenomenon is quite unmistakable. The two lines are as distinct and as distinctly parallel as possible. No draughtsman could draw them better. They are thoroughly Martian in their mathematical precision. At the very first glance, they convey, like all the other details of the canal system, the appearance of artificiality. It may be well to state this here definitely, for the benefit of such as, without having seen the canals, indulge in criticism about them. No one who has seen the canals well — and the *well* is all-important for bringing out the characteristics that give the stamp of artificiality, the straightness and fineness of the lines — would ever have any doubt as to their seeming artificial, however he might choose to blind himself to

the consequences. An element akin to the comic enters criticism based, not upon what the critics have seen, but upon what they have not. Books are reviewed without being read, to prevent prejudice; but it is rash to carry the same admirable broad-mindedness into scientific subjects.

In detail the doubles vary, chiefly, it would seem, in the distance the twin lines lie apart. In the widest I have seen, the Ganges, six degrees separate the two; in the narrowest, the Phison, four degrees and a quarter, — not a very great difference between the extremes. Four degrees and a quarter on Mars amount to 156 miles; six degrees, to 220. These, then, are the distances between the centres of the twin canals. Each canal seems a little less than a degree wide, or about 30 miles in the narrower instances; in the broader, a little more than a degree, or about 45 miles. Between the two lines, in the cases where the gemination, as it is called, is complete, lies reddish-ochre ground similar to the rest of the surface of the bright regions. Deducting the two half-widths of the bordering canals, we have, therefore, from 120 to 175 miles of clear country between the paralleling lines.

This gemination of a canal is certainly a passing strange phenomenon. Although, in steady air, the observation is not a difficult one, to see

the region where it occurs minutely enough for a sufficient length of time to mark the details of the process is another matter. I shall here give what I have been able to gather at the last opposition, and shall hope to add to it at the next. One element of mystery may be eliminated at the outset. The process is not so sudden as it seems. It is perceived of a sudden by the observer because of some specially favorable night. But it has been for some time developing. So much is apparent from my observations. Suggestions of duality occurred weeks before the thing stood definitely revealed. Furthermore, the gemination may lie concealed from the observer some time after it is quite complete, owing to lack of favorable atmospheric conditions. For it takes emphatically steady air to see it unmistakably.

The next point is, that the phenomenon is individual to the particular canal. Each canal differs from its neighbor not only in the distance the lines lie apart, but in the time at which duplication occurs. The event seems to depend both upon general seasonal laws governing all the duplications, and upon causes intrinsic to the canal itself. Within limits, each canal doubles at its own good time and after its own fashion. For example, although it seems to be a rule that north and south canals double before east and west ones, nevertheless, of two north

and south lines, one will double, the other will not, synchronously with a doubling running east and west; the same is true of those running at any other inclination.

Now this shows that the duplication is not an optical illusion at this end of the line; for, by any double refraction here, all the lines running in the same direction over the disk should be similarly affected, which they are not. On the contrary, there will be, say, two cases of doubling in quite different directions coexistent with several single canals that run the same way.

Nor is there any probability of its being a case of double refraction at the other end of the line, — that is, in the atmosphere of Mars; for in that case it is hard to see why all the lines should not be affected, to say nothing of the fact that, to render such double refraction possible, we must call upon a noumenon to help us out, as we know of no substance capable of the quality upon so huge a scale. Furthermore, what is cogent to the observer, though of no particular weight with his hearers, the phenomenon has no look of double refraction. It looks to be, what it undoubtedly is, a double existence.

Strengthening this conclusion is the mode of development of the doubling. This appears to take place in two ways, although it is possible

that the two are but different instances of one and the same process. Of the first kind, during this last opposition, the Ganges was an example.

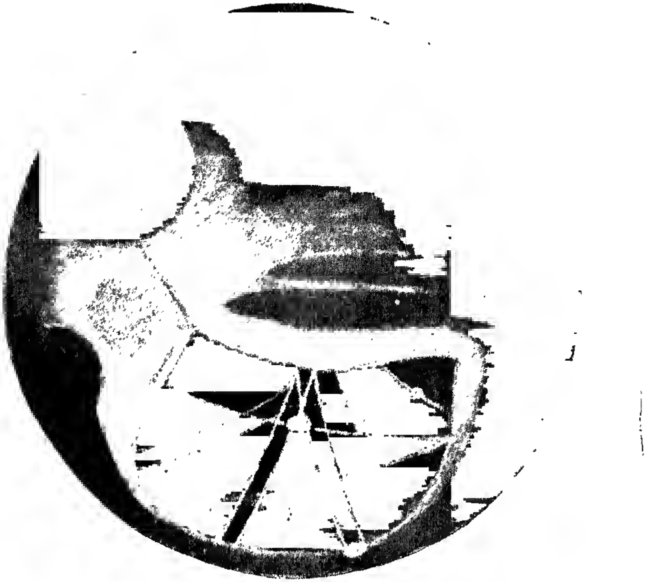
The Ganges was in an interesting protoplasmic condition during the whole of last summer. About to multiply by fission, it was not at first evident how this would take place. Hints of gemination were visible when I first looked at it in August. It showed then as a very broad but not dark swath of dusky color, of nearly uniform width from one extremity to the other, with sides suggestively even throughout. It is probable that they were then, as afterward, parallel, and that the slight convergence apparent at the bottom was due simply to foreshortening. The swath ran thus north-northwest all the way from the Gulf of the Dawn to the Lacus Labeatis. By moments of better seeing, its two sides showed darker than its middle; that is, it was already double in embryo, with a dusky middle-ground between the twin lines.

In October the doubling had sensibly progressed. The double visions were more frequent, and the ground between the twin lines had grown lighter. By November the doubling was unmistakable, and the mid-clarification had become nearly complete. It is to be remarked that the doubling did not involve the Fons Juventae and the canal leading to it, both of

which lay well to the right of the Ganges. The space included between the East and West Ganges was very wide, some six degrees. The canals themselves were, so far as could be seen, quite similar, and about a degree, or 37 miles, wide. Both started in the Gulf of the Dawn, and ran down to the lower Lake of the Moon, one entering each side of the lake or oasis. Two thirds of the way down, both similarly touched the sides of another oasis, an upper Lacus Lunae; the other I have called the Lacus Labeatis. The length of each canal was 1200 miles.

Except for fleeting suspicions of gemination, and for possible doublings like the parallelism of the two Hades, the next canal to show double was the Nectar, which was so seen by Mr. Douglass on October 4, and under still better seeing, a few minutes later, the doubling was detected by him extending straight across the Solis Lacus. In the Solis Lacus this was evidently a case of mid-clarification. What occurred in the Nectar seems more allied to the second class of manifestations, such as happened later with the Euphrates and the Phison.

Glimpses of a dual state in these canals we caught during the summer and autumn, but it was not till the November presentation of the region that they came out unmistakably twinned. On the 18th of that month, just as the twilight was fading away, the air being very still and



PHISON AND EUPHRATES
(Both double)
November 18, 1894

Lowell Observatory
Flagstaff, A. T. 1894

the definition exceptional, so soon as the sunset tremors subsided, the Euphrates and its neighbor the Phison I saw beautifully doubled, exactly like two great railroad tracks with bright ground between, each set extending down the disk for a distance of 1600 miles.

After that evening, whenever the seeing was good enough, they continued to present the same appearance. Now, with them no process of midway clarification, such as had taken place in the Ganges, had previously made itself manifest. They had, indeed, not been very well defined before duplication occurred, but apparently sufficiently so not to hide such broadening had it taken place; for, though the twin canals were not as far apart as the two Ganges, they were quite comparably distant, being, instead of six, about four and a quarter degrees from each other. Evidently, the process was, in the case of the Euphrates at least, under way in October, and even earlier, but was not well seen because the twin canals were not yet dark enough.

There seem, I may remark parenthetically, to be two other double canals in the region between the Syrtis Major and the Sabaeus Sinus, one to the east of the Phison, and another between the Phison and the Euphrates, both debouching at the same points as the Phison and the Euphrates themselves.

On the 19th of November I suspected duplication in the Typhon, another canal in the same region. It looked to be double, with dusky ground between.

On the 21st I similarly suspected the Jamuna and the Dardanus. Both looked broad and dusky, with very ill-defined condensation at the sides. But the seeing was not good enough. On the 22d I brought my observations to an end, in consequence of having to return East.

Exactly what takes place, therefore, in this curious process of doubling, I cannot pretend to say. It has been suggested that a progressive ripening of vegetation from the centre to the edges might cause a broad swath of green to become seemingly two. There are facts, however, that do not tally with this view. For example, the Ganges was always broad, but fainter, not narrower, earlier in the season. The Phison, on the other hand, went through no such process. Indeed, we are here very much in the dark, certainly very far off from what does take place in Martian canal gemination. Perhaps we may learn considerably more about it at the next opposition. At this the tendril end of our knowledge of our neighbor we cannot expect hard wood.

From these observations, and those of Schiaparelli, I feel, however, tolerably sure that the phenomenon is not only seasonal but vegetal.

Why it should take this form is one of the most pregnant problems about the planet. For it is the most artificial-looking phenomenon of an artificial-looking disk.

III. SPOTS IN THE DARK REGIONS.

To return now from these outposts of investigation to our main subject-matter, and to another phenomenon of more recent discovery than the double canals, and yet more suggestive of interpretation. We have seen what shows at one end of the canals, their inner end; namely, the oasis. But it seems that there is also something exceptional at the other. At the mouth of each canal, at the edge of the so-called seas, appears a curious dark spot, of the form of a half-filled angle; the sort of a mark with which one checks items on a list. Its form is singularly appropriate, according to mundane ideas, for it appears before the canal itself is visible, as if to mark the spot where the canal will eventually be. It lies in the so-called seas, and looks to be of the same color as they, but deeper in tint.

All the canals that debouch into the dark regions are provided with these terminal triangles, except those that lead out of long estuaries, like the Nilosyrtis, the Hiddekel, the Gihon, and so forth. The double canals are provided with twin triangles. That the triangular patches are phenomena connected with

the canals is evident from the fact that they never appear elsewhere. What exact purpose they serve is not so clear, but it would seem to be that of relay stations for the water before it enters the canals; what we see, upon this supposition, being, not the station or reservoir itself, but the specially fertile area round it.

That, in addition to being in a way oases themselves, they serve some such purpose as the above, is further hinted at by two facts: first, that whereas the oases develop, apparently, after the canals leading to them, the triangular spots develop before the canals that lead out of them; second, Mr. Douglass finds that it is in them that the canals in the dark regions terminate. They are the end of the one system at the same time that they are the beginning of the other. They would, therefore, seem to be way-stations of some sort on the road taken by the water from the polar cap to the equator.

Paralleling in appearance the oases in the bright regions are round spots that occur at the junctions of the canals in the dark ones. Speaking figuratively, these are the heads of the nails in the coffin of the idea that the seas are seas; since, if the blue-green color came from water, there could not be permanent darker dots upon it connected by equally dark streaks. Speaking unfiguratively, this shows that the whole system of canals and specially fertilized spots is not

confined to the deserts, but extends in a modified form over the areas of more or less vegetation.

There are thus two kinds of spots in the dark regions: those on their borders, and those in their midst. The position of the former — on the edge of the great deserts — implies a difference in kind, further emphasized by their shape. Following is the list of both kinds detected at Flagstaff: —

SPOTS IN THE DARK REGIONS.

Astrae Lacus.
Benacus Lacus.
Cynia Lacus.
Flevo Lacus.
Hesperidum Lacus.
Oxia Palus.
Spot at the mouth of the Phison.
" Euphrates.
" Daix on the Mare Icarium.
Spot at the mouth of the Daix on the Sabaeus Sinus.
Spot on the Socratis Promontorium.
Spot on the western side of the Socratis Promontorium.
" Margaritifer Sinus.
Spot at the mouth of the Jamuna on the Aurorae Sinus.
" Ganges "
" Hebe "
" Agathodaemon "
" Ambrosia on the Mare Australe.
" Maeander on the Aonius Sinus.
" Gorgon on the Mare Sirenum.
" Erinaeus.
" Titan on the Sinus Titanum.

Spot at the mouth of the	Cophen on the Mare Cimmerium.	
"	Laestrygon	"
"	Nereides	"
"	Cerberus	"
"	Chretes	"
"	Asopus on the Syrtis Major.	
"	Arosis	"
"	Typhon	"
Spot south of the mouth of the Typhon		"

We thus perceive that the blue-green areas are subjected to the same engineering system as the bright ones. In short, no part of the planet is allowed to escape from the all-pervasive trigonometric spirit. If this be Nature's doing, she certainly here runs her mathematics into the ground.

VI

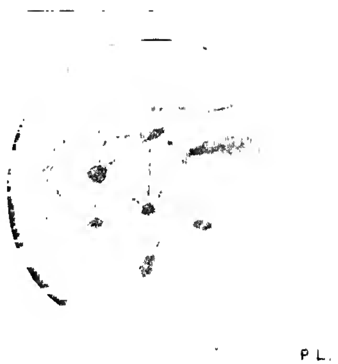
CONCLUSION

To review, now, the chain of reasoning by which we have been led to regard it probable that upon the surface of Mars we see the effects of local intelligence. We find, in the first place, that the broad physical conditions of the planet are not antagonistic to some form of life; secondly, that there is an apparent dearth of water upon the planet's surface, and therefore, if beings of sufficient intelligence inhabited it, they would have to resort to irrigation to support life; thirdly, that there turns out to be a network of markings covering the disk precisely counterparting what a system of irrigation would look like; and, lastly, that there is a set of spots placed where we should expect to find the lands thus artificially fertilized, and behaving as such constructed oases should. All this, of course, may be a set of coincidences, signifying nothing; but the probability points the other way. As to details of explanation, any we may adopt will undoubtedly be found, on closer acquaintance, to vary from the actual Martian state of things; for any Martian life must differ markedly from our own.

The fundamental fact in the matter is the dearth of water. If we keep this in mind, we shall see that many of the objeetions that spontaneously arise answer themselves. The supposed herculean task of construeting such eanals disappears at once; for, if the canals be dug for irrigation purposes, it is evident that what we see, and call by ellipsis the canal, is not really the canal at all, but the strip of fertilized land bordering it, — the thread of water in the midst of it, the canal itself, being far too small to be perceptible. In the case of an irrigation canal seen at a distance, it is always the strip of verdure, not the eanal, that is visible, as we see in looking from afar upon irrigated country on the Earth.

We may, perhaps, in conclusion, consider for a moment how different in its details existence on Mars must be from existence on the Earth. One point out of many bearing on the subjeet, the simplest and most eertain of all, is the effect of mere size of habitat upon the size of the inhabitant; for geometrical conditions alone are most potent factors in the problem of life. Volume and mass determine the force of gravity upon the surface of a planet, and this is more far-reaching in its effects than might at first be thought. Gravity on the surface of Mars is only a little more than one third what it is on the surface of the Earth. This would

Plate XXV



Nov. 5, 7h 23m–39m
long. 114°, lat. —22°

Nov. 5, 9h–9h 12m
long. 137°, lat. —22°

Nov. 6, 9h 14m.–21m
long. 142°, lat. —22°

Nov. 6, 10h 55m–11h 20m
long. 158°, lat. —22°

DRAWINGS OF THE PLANET IN 1894

Lowell Observatory
Flagstaff, A. T. 1894

work in two ways to very different conditions of existence from those to which we are accustomed. To begin with, three times as much work, as for example, in digging a canal, could be done by the same expenditure of muscular force. If we were transported to Mars, we should be pleasingly surprised to find all our manual labor suddenly lightened threefold. But, indirectly, there might result a yet greater gain to our capabilities; for if Nature chose she could afford there to build her inhabitants on three times the scale she does on Earth without their ever finding it out except by interplanetary comparison. Let us see how.

As we all know, a large man is more unwieldy than a small one. An elephant refuses to hop like a flea; not because he considers the act undignified, but simply because he cannot bring it about. If we could, we should all jump straight across the street, instead of painfully paddling through the mud. Our inability to do so depends upon the size of the Earth, not upon what it at first seems to depend, on the size of the street.

To see this, let us consider the very simplest case, that of standing erect. To this every-day feat opposes itself the weight of the body simply, a thing of three dimensions, height, breadth, and thickness, while the ability to accomplish it resides in the cross-section of the

muscles of the knee, a thing of only two dimensions, breadth and thickness. Consequently, a person half as large again as another has about twice the supporting capacity of that other, but about three times as much to support. Standing therefore tires him out more quickly. If his size were to go on increasing, he would at last reach a stature at which he would no longer be able to stand at all, but would have to lie down. You shall see the same effect in quite inanimate objects. Take two cylinders of paraffine wax, one made into an ordinary candle, the other into a gigantic facsimile of one, and then stand both upon their bases. To the small one nothing happens. The big one, however, begins to settle, the base actually made viscous by the pressure of the weight above.

Now apply this principle to a possible inhabitant of Mars, and suppose him to be constructed three times as large as a human being in every dimension. If he were on Earth, he would weigh twenty-seven times as much, but on the surface of Mars, since gravity there is only about one third of what it is here, he would weigh but nine times as much. The cross-section of his muscles would be nine times as great. Therefore the ratio of his supporting power to the weight he must support would be the same as ours. Consequently, he would be able to stand with as little fatigue as we. Now

consider the work he might be able to do. His muscles, having length, breadth, and thickness, would all be twenty-seven times as effective as ours. He would prove twenty-seven times as strong as we, and could accomplish twenty-seven times as much. But he would further work upon what required, owing to decreased gravity, but one third the effort to overcome. His effective force, therefore, would be eighty-one times as great as man's, whether in digging canals or in other bodily occupation. As gravity on the surface of Mars is really a little more than one third that at the surface of the Earth, the true ratio is not eighty-one, but about fifty; that is, a Martian would be, physically, fifty-fold more efficient than man.

As the reader will observe, there is nothing problematical about this deduction whatever. It expresses an abstract ratio of physical capabilities which must exist between the two planets, quite irrespective of whether there be denizens on either, or how other conditions may further affect their forms. As the reader must also note, the deduction refers to the possibility, not to the probability, of such giants; the calculation being introduced simply to show how different from us any Martians may be, not how different they are.

It must also be remembered that the question of their size has nothing to do with the

question of their existence. The arguments for their presence are quite apart from any consideration of avoirdupois. No Herculean labors need to be accounted for; and, if they did, brain is far more potent to the task than brawn.

Something more we may deduce about the characteristics of possible Martians, dependent upon Mars itself, a result of the age of the world they would live in.

A planet may in a very real sense be said to have life of its own, of which what we call life may or may not be a subsequent detail. It is born, has its fiery youth, sobers into middle age, and just before this happens brings forth, if it be going to do so at all, the creatures on its surface which are, in a sense, its offspring. The speed with which it runs through its gamut of change prior to production depends upon its size; for the smaller the body the quicker it cools, and with it loss of heat means beginning of life for its offspring. It cools quicker because, as we saw in a previous chapter, it has relatively less inside for its outside, and it is through its outside that its inside cools. After it has thus become capable of bearing life, the Sun quickens that life and supports it for we know not how long. But its duration is measured at the most by the Sun's life. Now, inasmuch as time and space are not, as some philosophers have from their too mundane stand-

point supposed, forms of our intellect, but essential attributes of the universe, the time taken by any process affects the character of the process itself, as does also the size of the body undergoing it. The changes brought about in a large planet by its cooling are not, therefore, the same as those brought about in a small one. Physically, chemically, and, to our present end, organically, the two results are quite diverse. So different, indeed, are they that unless the planet have at least a certain size it will never produce what we call life, meaning our particular chain of changes or closely allied forms of it, at all. As we saw in the case of atmosphere, it will lack even the premise to such conclusion.

Whatever the particular planet's line of development, however, in its own line, it proceeds to greater and greater degrees of evolution, till the process stops, dependent, probably, upon the Sun. The point of development attained is, as regards its capabilities, measured by the planet's own age, since the one follows upon the other.

Now, in the special case of Mars, we have before us the spectacle of a world relatively well on in years, a world much older than the Earth. To so much about his age Mars bears evidence on his face. He shows unmistakable signs of being old. Advancing planetary years have left their mark legible there. His continents are all

smoothed down; his oceans have all dried up. *Teres atque rotundus*, he is a steady-going body now. If once he had a chaotic youth, it has long since passed away. Although called after the most turbulent of the gods, he is at the present time, whatever he may have been once, one of the most peaceable of the heavenly host. His name is a sad misnomer; indeed, the ancients seem to have been singularly unfortunate in their choice of planetary cognomens. With Mars so peaceful, Jupiter so young, and Venus bashfully draped in cloud, the planet's names accord but ill with their temperaments.

Mars being thus old himself, we know that evolution on his surface must be similarly advanced. This only informs us of its condition relative to the planet's capabilities. Of its actual state our data are not definite enough to furnish much deduction. But from the fact that our own development has been comparatively a recent thing, and that a long time would be needed to bring even Mars to his present geological condition, we may judge any life he may support to be not only relatively, but really older than our own.

From the little we can see, such appears to be the case. The evidence of handicraft, if such it be, points to a highly intelligent mind behind it. Irrigation, unscientifically conducted, would not give us such truly wonderful mathematical

PLATE XXVI

P L

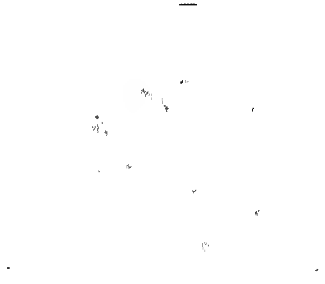
Nov. 10, 9h 57m–10h 18m
long. 112°, lat. —22°

P L

Nov. 10, 10h 32m–37m
long. 117°, lat. —22°

P L

Nov. 10, 10h 50m–11h
long. 122°, lat. —22°



P L

Nov. 10, 11h 7m–15m
long. 126°, lat. —22°

DRAWINGS OF THE PLANET IN 1894

LOWELL OBSERVATORY
Flagstaff, A. T. 1894

fitness in the several parts to the whole as we there behold. A mind of no mean order would seem to have presided over the system we see, — a mind certainly of considerably more comprehensiveness than that which presides over the various departments of our own public works. Party politics, at all events, have had no part in them; for the system is planet wide. Quite possibly, such Martian folk are possessed of inventions of which we have not dreamed, and with them electrophones and kinetoscopes are things of a bygone past, preserved with veneration in museums as relics of the clumsy contrivances of the simple childhood of the race. Certainly what we see hints at the existence of beings who are in advance of, not behind us, in the journey of life.

Startling as the outcome of these observations may appear at first, in truth there is nothing startling about it whatever. Such possibility has been quite on the cards ever since the existence of Mars itself was recognized by the Chaldean shepherds, or whoever the still more primeval astronomers may have been. Its strangeness is a purely subjective phenomenon, arising from the instinctive reluctance of man to admit the possibility of peers. Such would be comic were it not the inevitable consequence of the constitution of the universe. To be shy of anything resembling himself is part and par-

cel of man's own individuality. Like the savage who fears nothing so much as a strange man, like Crusoe who grows pale at the sight of footprints not his own, the civilized thinker instinctively turns from the thought of mind other than the one he himself knows. To admit into his conception of the cosmos other finite minds as factors has in it something of the weird. Any hypothesis to explain the facts, no matter how improbable or even palpably absurd it be, is better than this. Snow-caps of solid carbonic acid gas, a planet cracked in a positively monomaniacal manner, meteors ploughing tracks across its surface with such mathematical precision that they must have been educated to the performance, and so forth and so on, in hypotheses each more astounding than its predecessor, commend themselves to man, if only by such means he may escape the admission of anything approaching his kind. Surely all this is puerile, and should as speedily as possible be outgrown. It is simply an instinct like any other, the projection of the instinct of self-preservation. We ought, therefore, to rise above it, and, where probability points to other things, boldly accept the fact provisionally, as we should the presence of oxygen, or iron, or anything else. Let us not cheat ourselves with words. Conservatism sounds finely, and covers any amount of ignorance and fear.

We must be just as careful not to run to the other extreme, and draw deductions of purely local outgrowth. To talk of Martian beings is not to mean Martian men. Just as the probabilities point to the one, so do they point away from the other. Even on this Earth man is of the nature of an accident. He is the survival of by no means the highest physical organism. He is not even a high form of mammal. Mind has been his making. For aught we can see, some lizard or batrachian might just as well have popped into his place early in the race, and been now the dominant creature of this Earth. Under different physical conditions, he would have been certain to do so. Amid the surroundings that exist on Mars, surroundings so different from our own, we may be practically sure other organisms have been evolved of which we have no cognizance. What manner of beings they may be we lack the data even to conceive.

For answers to such problems we must look to the future. That Mars seems to be inhabited is not the last, but the first word on the subject. More important than the mere fact of the existence of living beings there, is the question of what they may be like. Whether we ourselves shall live to learn this cannot, of course, be foretold. One thing, however, we can do, and that speedily: look at things from a standpoint raised above our local point of view;

free our minds at least from the shackles that of necessity tether our bodies; recognize the possibility of others in the same light that we do the certainty of ourselves. That we are the sum and substance of the capabilities of the cosmos is something so preposterous as to be exquisitely comic. We pride ourselves upon being men of the world, forgetting that this is but objectionable singularity, unless we are, in some wise, men of more worlds than one. For, after all, we are but a link in a chain. Man is merely this earth's highest production up to date. That he in any sense gauges the possibilities of the universe is humorous. He does not, as we can easily foresee, even gauge those of this planet. He has been steadily bettering from an immemorial past, and will apparently continue to improve through an incalculable future. Still less does he gauge the universe about him. He merely typifies in an imperfect way what is going on elsewhere, and what, to a mathematical certainty, is in some corners of the cosmos indefinitely excelled.

If astronomy teaches anything, it teaches that man is but a detail in the evolution of the universe, and that resemblant though diverse details are inevitably to be expected in the host of orbs around him. He learns that, though he will probably never find his double anywhere, he is destined to discover any number of cousins scattered through space.

APPENDIX

Note I

The critical velocity at the surfaces of the planets is found as follows: —

Using the usual symbols we have:

$$fdt = dv$$
$$\therefore\ fds = vdv.$$

And as $f = \frac{-m}{s^2}$, since the force tends to decrease the coördinates, this becomes $-\frac{mds}{s^2} = vdv$.

Integrating:

$\frac{m}{s} = \frac{1}{2} v^2 + c$, of which the definite integral from s_1 to s_2 is

$\frac{m}{s_1} - \frac{m}{s_2} = \frac{1}{2} v_1^2 - \frac{1}{2} v_2^2$.

Hence, since at infinity the velocity is 0, the equation for a fall to a planet's surface from infinity is

$$\frac{m}{r} = \frac{1}{2} v^2,$$

r being the radius of the planet and v the velocity acquired at its surface from a fall from infinity, which is the same as the velocity needed for projection from its surface to infinity.

To find m we have in the case of the Earth $g = 32$ ft. a second at its surface; this gives us m in terms of g, that is, f. For the other planets we need only to introduce their masses and radii in terms of those of the Earth and then multiply the value for the Earth by the square root of the ratio.

The result is that we find the critical velocity for the several planets and for the Sun to be as follows: —

Mercury	2.2 miles a second (probable value).
Venus	6.6 " " " " "
Earth	6.9 " " "
Moon	1.5 " " "

Mars	3.1 miles a second.	
Jupiter	37. " " "	(mean value).
Saturn	22. " " "	" "
Uranus	13. " " "	" "
Neptune	14. " " "	" "
Sun	382. " " "	

While the probable maximum speed of the molecules of some of the commoner gases at 0° Cent. are as follows: —

Hydrogen	7.4 miles a second.
Water vapor	2.5 " " "
Nitrogen	2.0 " " "
Oxygen	1.8 " " "
Carbonic dioxide	1.6 " " "

Note II

The change in the apparent size of the equatorial diameter as compared with the polar one as the phase increased, suggesting the unconscious measurement of a twilight upon the planet, becomes still more striking when, in addition to the October-November measures mentioned in the text, the measures from July to October are considered in connection with them. Tabulated chronologically, the whole are as follows: —

MEANS

Polar Diameters

	Cor. for ref. irr. tilt and phase Irr. 0″.10	Prob. error	Angle of phase	Cor. for ref. irr. tilt and phase Irr. 0″.15
July (6 to 22 inc.)	9.976	0″.13	0°	9.933
Aug. (11 to 21 inc.)	9.362	0″.04	0°	9.325
Sept. (20 to Oct. 5 inc.)	9.401	0″.012	0°	9.355
Oct. (12 & 24 to 30 inc.)	9.375	0″.028	1°	9.336
Oct. (15 to 23 inc.)	9.379	0″.011	2°.5	9.339
Oct. (12 & 24 to 30 inc.)	9.375	0″.028	1°	9.336
Nov. (2 to 21 inc.)	9.390	0″.012	4°	9.350

Equatorial Diameters

July (6 to 22 inc.)	9.691	9.680	0″.11	0″.08	46°.5	9.672
Aug. (11 to 21 inc.)	9.666		0″.15		41°	9.645
Sept. (20 to Oct. 5)	9.523		0″.010		20°.5	9.490
Oct. (12 & 24 to 30 inc.)	9.457		0″.016		7°	9.417
Oct. (15 to 23 inc.)	9.429		0″.010		1°	9.385
Oct. (12 & 24 to 30 inc.)	9.457		0″.016		7°	9.417
Nov. (2 to 21 inc.)	9.545		0″.015		19°	9.514

It will be seen that, except for the July value, the size of the polar diameter comes out essentially the same throughout. Now, during July the polar cap was very large, and covered the southern part of the disk at the point where the polar diameter was measured. As it was much brighter than the rest of the disk, its irradiation must have been correspondingly great, and this would have had the effect of increasing the apparent length of the polar diameter beyond its true value.

The equatorial measures, on the other hand, show a systematic increase as the phase increased; and they do this on both sides of opposition. The increase, it will be noticed, is much greater than the probable errors of observation.

Note III

As the statement has been widely circulated that recent spectroscopic observations negative an atmosphere on Mars, it may be well to mention in a note that the observations in question neither affirm nor deny its presence, as their self-disclosed measure of precision, ¼ of an atmosphere, proves them incapable of it. They simply concur in showing that atmosphere to be thin. As a matter of fact, if spectroscopic observations did deny the existence of an atmosphere on Mars, such assertion would be fatal, not to the atmosphere, but to the observer or his instrument, as the existence of an atmosphere is demonstrated by the fundamental laws of

physics, inasmuch as no change could take place on the planet's surface without it, and that changes do take place is undeniable. (See page 31 *et seq.*)

Note IV

Mars has two satellites, discovered by Hall in 1877, and known as Deimos (Dread) and Phobos (Fear), named in keeping with the God of War.

Deimos, at a distance of 14,600 miles from the planet's centre, makes his circuit in 30 hours and 18 minutes; Phobos, at a distance of 5,800, in 7 hours and 39 minutes. As Mars himself rotates in 24 hours and 39 minutes, Phobos goes round the planet faster than the planet turns upon itself, and, in consequence, would appear to any observers on the planet's surface to break the otherwise universal conformity of stellar motions by rising in the west and setting in the east. Deimos, too, is just as unconventional in its way, for it remains for two days at a time about the horizon. Furthermore, with each, owing to its nearness to the planet, its distance from any place on the surface varies at different times, and with its distance varies its apparent size in a somewhat startling manner.

As for themselves, they are very minute bodies, though not so difficult to see as is commonly stated. In the clear air of Arizona, both were conspicuous objects. They appear as stars of about the 12th and 10th magnitudes respectively; Phobos being much larger, relatively to Deimos, than its hitherto accepted value would indicate. Observations at Flagstaff by both Mr. Douglass and by me agree in making its relative brilliancy such as to give it a diameter about 3.6 times that of Deimos. It is not usually so conspicuous as Deimos, in spite of its size, because of its proximity to the planet, and the consequent much greater illumination of the field upon which it is seen. Considering their most probable albedoes as somewhat less than that of our moon,

we find from their stellar magnitudes, taking the stellar magnitude found for Deimos by Pickering in 1877 as basis, their diameters to be, —

Deimos, about 10 miles ;
Phobos, about 36 miles.

Phobos would thus, at its closest approach to the surface of the planet, that is, when it was in the zenith, just show a disk like the Moon. Otherwise both satellites would appear as stars.

Neither satellite shares the red tint of the planet.

Note V.

As the means employed in any astronomical observation are of interest, I may add that the telescope used in these researches was an 18-inch refractor, made by Brashear, of Alleghany, Pa., the largest he has yet made. The powers used varied from 320 to 1305 diameters, the usual ones being, for visual purposes, 440 and 617, and, for micrometric measurements, 862. There is, not unnaturally, much misconception prevalent as to the magnification possible in a telescope. The highest powers of a glass can never be used on planetary detail, as the tremors of the air blur the image. Thus we come back again to the question of atmosphere, which is indeed the *crux observationis*. With regard to work on the planets, the important point about an observatory is not so much what is its lens as what is its location.

INDEX OF NAMES ON THE MAP OF MARS

ARRANGED ALPHABETICALLY

REGIONS

No.	Name
100	Aonius Sinus
7	Argyre
168	Atlantis
15	Aurorae Sinus
287	Ausonia
4	Deucalionis Regio
268	Edom Promontorium
194	Elysium
1	Fastigium Aryn
229	Hadriaticum Mare
240	Hammonis Cornu
275	Hellas
211	Hesperia
205	Isidis Regio
236	Japygia
225	Lemuria
207	Libya
176	Mare Chronium
165	Mare Cimmerium
285	Mare Erythraeum
283	Mare Icarium
173	Mare Sirenum
210	Mare Tyrrhenum
20	Margaritifer Sinus
103	Memnonia
6	Noachis
277	Oenotria
88	Ogygis Regio
286	Ophir
9	Protei Regio
5	Pyrrhae Regio
3	Sabaeus Sinus
2	Socratis Promontorium
233	Syrtis Major
237	S[illegible] Promontorium
209	Syrtis Parva
27	Tempe
92	Thyle I.
177	Thyle II.
267	Xisuthri

CANALS

No.	Name
271	Acalandrus
84	Acampsis
10	Acesines
119	Achana
222	Achates
199	Achelous
284	Acheron
90	Acis
238	Aeolus
76	Aesis
192	Aethiops
43	Agathodaemon
273	Alpheus
87	Ambrosia
203	Amenthes
12	Amphrysus
54	Amystis
61	Anapus
161	Antaeus
242	Anubis
79	Araxes
144	Arges
244	Aresis
250	Arsanias
62	Artanes
243	Asopus
245	Astaboras
204	Astapus
156	Atax
224	Athesis
163	Avernus
78	Avus
162	Axius
148	Axon
57	Bactrus
37	Baetis
86	Bathys
159	Bautis
143	Belus
198	Boreas
201	Boreosyrtis
129	Brontes
16	Caicus
189	Cambyses
22	Cantabras
232	Carpis
239	Casuentus
55	Catarrhactes
94	Cayster
221	Centrites
218	Cephissus
186	Cerberus
14	Cestrus
182	Chaboras
184	Chretes
42	Chrysas
49	Chrysorrhoas
212	Cinyphus
47	Clitumnus
64	Clodianus
160	Cophen
44	Coprates
40	Corax
164	Cyaneus
91	Cyrus
77	Daemon
260	Daix
258	Daradax
26	Dardanus
19	Dargamanes
264	Deuteronilus
172	Digentia
235	Dosaron
93	Drahonus
107	Elison
74	Eosphorus
18	Eranneboas
150	Erebus
141	Erinaeus
226	Erymanthus
104	Erynnis
256	Eulaeus
114	Eumenides
193	Eunostos
253	Euphrates
140	Eurymedon
213	Eurypus
142	Evenus
67	Fortunae
179	Gaesus
215	Galaesus
197	Galaxias
36	Ganges
48	Ganymede
13	Garrhuenus
122	Gigas
266	Gihon
63	Glaucus
105	Gorgon
145	Gyes
153	Hades
70	Halys
170	Harpasus
38	Hebe
181	Helisson

OASES

INDEX OF NAMES ON THE MAP OF MARS

ARRANGED NUMERICALLY

INDEX